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**RESEARCH TECHNIQUES FOR ASSESSMENT OF
LUBRICANT DEGRADATION, LUBRICANT DEWETTING,
AND SLIP-RING WEAR**

SLIP RING RIG PAGES 5-7 & 53-64

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AIR FORCE MATERIALS LABORATORY
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FOREWORD

This report was prepared by Battelle's Columbus Division, 505 King Ave., Columbus, Ohio 43201, for Air Force Materials Laboratory, Nonmetallic Materials Division, Lubricants and Tribology Branch, under contract F33615-73-C-5087, which was initiated under Project Nr 7343, "Aerospace Lubricants."

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This technical report has been reviewed and is approved.



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ABSTRACT

Three experimental apparatuses have been designed, constructed, and delivered to the Air Force Materials Laboratory. These apparatuses will be used to develop experimental data which can be used to devise accelerated life tests for bearings and slip rings for mechanically despun antenna drive systems for Air Force communications satellites. Two apparatuses were designed for the purposes of studying lubricant degradation and dewetting in ball bearings operating in vacuum. The third apparatus was designed to evaluate lift tests for slip rings operating in vacuum.

The report appendices contain operating instructions for the various apparatuses.

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I

INTRODUCTION

The Air Force is now in the design and development stages of a program that is intended to produce communications satellites that will operate with life expectancies of not less than 10 years and capabilities of up to 20 years. Due to the simplicity of design and successful operating experience, it is highly probable that future Air Force satellites will use mechanically despun antennas. Testing of components on a real-time basis would not be feasible. It is necessary to develop test methodology for short-term life tests. The objective of this program has been to design and construct three fixtures having the necessary features to permit the investigation and development of accelerated life tests. Two of the fixtures were built for the purpose of studying bearings and lubricants that are associated with mechanical drive systems for the antenna. With one fixture, lubricant degradation failure mechanisms can be studied; with the other, lubricant dewetting failure mechanisms can be investigated. The third, a slip-ring fixture, was designed and built for the purpose of evaluating ring and brush performance.

II

SUMMARY

Chemical changes in the lubricant can take place due to operation over extended periods of time. Some that might be expected include changes in lubricant composition and additive concentration. "Friction polymer" formation which is probably caused by a high localized flash temperature has been observed in the contact region. Physical changes such as viscosity loss may also occur. The bearing fixtures have been designed with features that will permit monitoring of performance parameters sensitive to lubricant degradation. These include precision-drive systems, ultrasensitive loading mechanisms, dual torque-measuring transducers, temperature-detection capabilities, and the capability of using vapor-deposited load- and temperature-sensing transducers which can be applied to the contacting surfaces of the bearing.

In other tests it has been observed that for bearings operated in vacuum, dewetting of surfaces has taken place. The effect of such lubricant starvation must be defined in terms of its influence on bearing performance and lifetime. An optical viewport has been built into the bearing fixture so as to permit the viewing or photographing of test-bearing surfaces while in operation. This will allow dewetting to be identified when it occurs without removal of the bearings from the vacuum environment.

Wear rate of dry or lubricated electrical slip rings must be measured and understood in order to evaluate life-test methods. Several rate functions must be considered and long-term changes must be factored into the evaluations. The slip-ring fixture can be used to study and evaluate slip-ring materials, slip-ring brush design, and the effects of various lubricants on wear. Capabilities for measuring or assessing electrical conductivity, friction or torque, temperature, and wear accumulation (through use of a 6-inch-diameter viewport) have been included in this fixture.

III

DESCRIPTION OF BEARING FIXTURES

Test Chambers

The two bearing fixtures are alike in all details. The housing or test chamber is a self-contained unit which connects to a standard ultrahigh vacuum pumping system via a 6-inch metal gasketed flange. The chambers have been constructed entirely from 304 stainless steel and strict compliance to high-vacuum welding and machining procedures has been followed. All openings have been provided with standard bakeable high-vacuum flanges which use soft copper gaskets. The assembled chambers were vacuum leak checked and found to have capabilities of 10^{-8} torr or better.

Test-Bearing-Support Mechanisms

The test bearing is supported in the horizontal position by a bearing outer race adapter plate which in turn is mounted in the bearing support rotor. Adapters can be made that will provide a test bearing size range from 40- to 120- bore. The support rotor is both rotated and supported by a model SB-750 modified FERROFLUIDIC vacuum-sealing, mechanical feedthrough. Modifications to the feedthroughs were performed by the manufacturer and consist of the following:

- (1) Machining of a 1/2-inch hole (axially) through the shaft
- (2) Shortening of the shaft extension to 1-3/8 inches on vacuum side only
- (3) Grinding of precision centers in both ends of the shaft
- (4) Machining of flats on both ends of shaft in place of keyways

- (5) Removal of O-ring seals and welding of static seals to body
- (6) Certifying 0.1 mil total indicated shaft runout
- (7) Replacement of a standard bearing pair with a FAFNIR super-precision matched pair.

Each feedthrough is installed in its respective 8-inch vacuum flange which constitutes the bottom end of the test chamber. After vacuum leak checking each flange assembly, the bearing support rotor was installed on the feed-through shaft using an interference shrink-fit technique. This assembly was then mounted in a precision lathe and all critical surfaces were turned true to the shaft centers. The outer race adapter was then fitted to its rotor and its surfaces were also trued to the shaft centers. These designs and methods of assembly and machining have produced a bearing support system of very high quality with regard to runout and smoothness.

DC Motor and Control

The vacuum sealing feedthrough is driven by a REX NORD No. 62 flexible disk coupling attached to a Printed Motors Inc. motor tachometer (No. U16M4T).^{*} The motor and coupling are held in proper alignment by a stand-off mounting support. Power and speed control for the motor is furnished by a CONTROL SYSTEMS RESEARCH, Inc., dc servo controller (Type NC102F).^{*} With this motor-controller combination the system can be operated over a speed range which is from less than 10 to above 1800 r/min with an accuracy of 0.01 percent.

Test-Bearing Loading System

The test-bearing axial load is applied through a mechanically adjustable spring arrangement from the outside of the chamber. This can be adjusted while the bearing is rotating. The load arm extends through the chamber and is sealed by a bellows assembly which provides movement capabilities to the arm. The arm is supported on the outside of the chamber by two pillow blocks and a clamping mechanism. A single tapered leaf spring is attached to the load arm assembly at 90 degrees. The opposite end of the spring rests against an adjusting screw. This screw has a knob for turning and a large handwheel (nut) for locking it into position. Strain gages are mounted on the spring to produce a means of monitoring and calibrating the load. The load arm is attached to the inner race of the test bearing through a load-arm extension and a short length of music wire. One end of the wire is clamped to the load arm extension and the other to the inner-race adapter-ring loading plate. The wire is positioned on the axial centerline of the bearing and provides for high sensitivity of inner-race rotational movement. The wire clamp

^{*} Appendix I.

on the inner-race adapter plate is equipped with ceramic clamping jaws which insulate the inner race electrically. This facilitates conductivity measurements between the inner- and outer-race components for qualitative film-thickness assessment.

Temperature-Measuring Capabilities

Each bearing fixture has been provided with a CERAMASEAL chromel-alumel thermocouple feedthrough. This unit is mounted on the outside end of the load arm and its inside lead wires pass through the center of the load arm and are insulated electrically from the system by lengths of glass tubing. A thermocouple can be placed anywhere inside the chamber and attached to these leads. These lead wires might also be used to make electrical-continuity measurements.

Torque-Measuring System

Torque and torque ripple in the test bearing are monitored through the use of a dual SCHAEVITZ linear variable differential transformer system. As the outer race of the bearing is rotated, the inner race will have some tendency to follow it due to the friction and viscous drag between the bearing parts. The inner-race adapter plate can respond to this force because of the high flexibility of the loading (music) wire mentioned previously. An arm has been attached to the adapter plate which holds both a calibrated (flat) restraining spring and the movable cores of the differential transformers. Through calibration techniques, torque and torque ripple can be evaluated. A DAYTRONIC 300 D transducer amplifier containing a Type 70 input module may be used as the signal conditioner and readout or to supply input to a millivolt recorder.

Bearing View Port

An INTERNATIONAL TELEPHONE AND TELEGRAPH window assembly (No. 609834-2)* has been placed in each test chamber top flange. The window position is directly above the test bearing. Dewetting of the bearing surfaces can be studied through this port and other conditions visible during operation of the bearing can be monitored.

*ITT-ELECTRON TUBE DIVISION, 3700 E. Pontiac St., Fort Wayne, Indiana 46803.

Vacuum Gage Mounting

A nude ion gage (VARIAN) has been installed in a 1-1/2-inch-diameter x 2-inch-long port located on the side of the load-arm housing. This will permit monitoring the test chamber pressure at a point very close to the bearing under test.

IV

DESCRIPTION OF SLIP-RING FIXTURE

Test Chamber

All components of the fixture are contained in a bakeable 304 stainless steel chamber. Operation requires only that the chamber be connected through the front 6-inch flange to a standard high-vacuum pumping system. All other openings into the chamber are sealed with similar soft-copper gasket-type high-vacuum bakeable flanges. Strict conformity to high-vacuum-system welding and machining procedures was followed throughout construction.

Vacuum Feedthrough and Drive System

An SB-500-A-N-069 FERROFLUIDIC rotary feedthrough has been selected as the means of transmitting the driving power from the the dc motor on the outside of the chamber to the slip-ring device on the inside. A PRINTED MOTORS INC. No. U16M4T motor tachometer is used to drive the feedthrough and a CONTROL SYSTEMS RESEARCH No. NC102F dc servo controller is employed to effect motor speed regulation or control. (The latter component is common for the three test fixtures supplied; i.e., it may be connected to any one test fixture.) With this combination a wide range of speeds are available for the fixture. Throughout a range of speeds from below 10 rpm to full motor speed (~1800 r/min) a regulation of 0.01 percent can be maintained.

Two REX NORD style CM (Size 62) miniature flexible disk couplings are used to transmit power from the motor to the FERROFLUIDIC feedthrough and from the feedthrough to the slip-ring device on the inside of the chamber.

The Slip-Ring Device

The slip-ring device is a flange-mounted bolt-on unit that can be removed from the fixture for inspection, disassembly, adjustment, or modifications. Special attention has been given to making this device versatile and adaptable

to a wide range of instrumentation systems. The MAIN FRAME is a 304 stainless steel welded assembly. This frame is bolted to a stand-off flange which in turn is bolted to the bottom flange of the test chamber. The slip-ring shaft, made from M-50 steel, has been machined to close tolerances which provides high stability and minimum runout for the slip rings. Six ELECTRO-TEC CORP. slip rings have been mounted on the shaft. BARDEN precision instrument bearings are used to support the shaft assembly in the MAIN FRAME. A spring-loaded end cap holds the shaft assembly in place and provides preload to the bearings. Brush-block assemblies, also supplied by ELECTRO-TEC CORP., are mounted on flexible supports. These supports are attached to the MAIN FRAME through a common mounting bracket. The device also contains an enclosing glass outer sleeve. This is sealed at both ends by O-ring gaskets. Gas exchange can occur through the bearing at the drive end of the slip-ring device. A lubricant reservoir can be installed behind the slip rings when required.

Friction-Measuring Instrumentation

Friction or torque measurements between slip-ring and brush assemblies are made feasible through three SCHAEVITZ 050 HPA linear-displacement transducers mounted on the MAIN FRAME. Clamps around the transducer coil assemblies permit proper alignment and null point location. The transducer cores are connected to the flexible supports holding the brush blocks. With proper adjustment and calibration the system gives a high sensitivity to frictional forces between the slip rings and the brushes. A Daytronic 300D transducer amplifier with a Type 70 input module is used to assess the friction forces.

Each brush block has two independent wire brushes which are each connected to a terminal lug on the top surface of the block. By connecting a resistance measuring circuit to the terminals, electrical continuity between the brushes and ring can be monitored. Teflon®-covered leads have been installed on the brush-block assemblies for this purpose. These connect to an 8-lead, bakeable vacuum feedthrough installed in the bottom flange of the chamber.

Temperature-Measuring Capabilities

A CERAMASEAL 808 B 8339-1 chromel-alumel feedthrough has been installed in the 1-1/2-inch vacuum flange on the left side of the test chamber. A thermocouple can be attached to the feedthrough inside leads and in turn placed at any location inside the fixture. A quick-disconnect plug is provided on the outside.

Slip-Ring View Port

Opposite the vacuum pumping flange, another 6-inch flange has been provided. A standard ULTEK vacuum-sealed glass window is installed on this flange. This port is large enough to permit observation of the slip-ring device while in operation and when installing the test chamber base flange to the test chamber. Orientation (circumferentially) can be made to permit viewing of the slip-ring device from any angle. It is also feasible to mount the complete fixture in the horizontal position on the vacuum pump. In this position, wear debris could be collected on the glass sleeve surrounding the slip-ring device and monitored through the viewing port.

Vacuum Gage Mounting

A 1-1/2-inch standard vacuum flange has been placed in the test chamber on the lower right side. A nude ion gage (VARIAN) has been installed in this opening so that pressure near the slip-ring device can be monitored.

V

ASSEMBLY AND OPERATION OF FIXTURES

Three assembly and operation manuals have been prepared and two copies of each are being supplied with this report in the appendices. One covers the two bearing fixtures, one covers the slip-ring fixture, and one gives instructions for mounting and operating the motor-controller drive system which is common to all three fixtures. More detailed descriptions with graphs, sketches, and pictures of components, their function, operation, and calibration are to be found in these manuals.

APPENDIX I

INSTRUCTION MANUAL for MOTOR CONTROL SYSTEM

INTRODUCTION

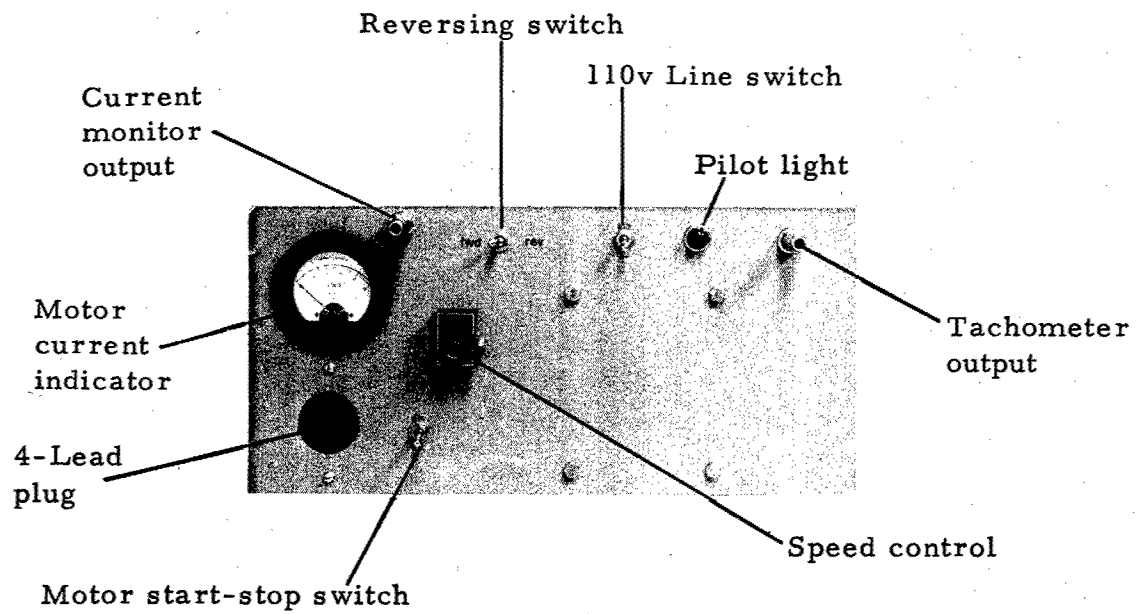
Each of the three fixtures uses a PRINTED MOTORS INC. (PMI) motortachometer (No. U16M4T) unit to drive the test specimens. All three motors have identical input cords and plugs. A single servo controller (CONTROL SYSTEMS RESEARCH Model NC102) is used to supply power to any of the motors. Front and rear views of the controller are illustrated in FIGURE 1. With this power supply, a wide range of controlled motor speeds is possible. Motor speed from less than 10 rpm to greater than 1800 rpm can be controlled to within 0.01 percent of set speed.* Procedures for the mounting and operation of motors and for the operation of the control system are as follows.

Mounting of Motors

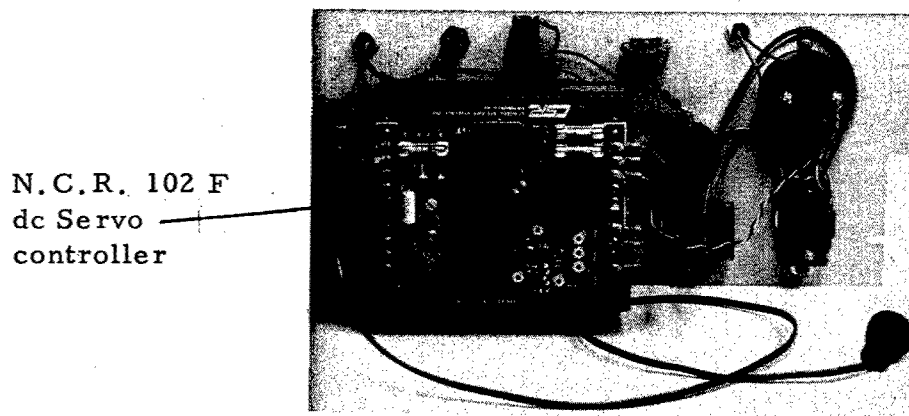
All three motors are mounted in the same manner. A stand-off flange supports the motor below the test-fixture vacuum chamber and provides room for the Rex Nord drive coupling. To mount the motor, the following steps should be taken.

- (1) Mount motor on stand-off flange and lock in place with four 1/4-in. bolts.
- (2) Turn the vacuum fixture upside down so the Ferrofluidic feedthrough shaft is pointing up.
- (3) Place the proper shaft alignment sleeve over the feed-through shaft. (Sleeve is furnished.)
- (4) Place motor shaft in the sleeve and lower motor assembly into position onto bottom flange of the test fixture.
- (5) Bolt the stand-off to the bottom flange using three 3/8-in. bolts. Note that the bolt holes in this end of the stand-off are oversize. This permits movement for shaft alignment.
- (6) Remove the motor from the stand-off then remove the shaft alignment sleeve from the feedthrough shaft.

* Refer to the attached technical manual . . . TM-1014.



Front



Rear

FIGURE 1. DC MOTOR CONTROL PANEL

- (7) Install REX NORD coupling on feedthrough shaft. One setscrew of the coupling should be positioned over the flat or groove on the shaft. A lead shot should be placed under the other setscrew to protect the shaft from surface damage. Access holes have been provided in the stand-off walls so that an Allen wrench can be operated in these setscrews.
- (8) Reinstall motor in stand-off tube. Care must be taken not to damage the coupling during this assembly. Install setscrews and lead shot as described previously.
- (9) Turn fixture right side up.
- (10) Check wiring diagram shown in FIGURE 2 for proper hookup of leads.

Operation of Servo Motor Control System

As shown in FIGURE 1, all control components have been mounted on a standard instrument cabinet panel which is compatible with currently used equipment at the AIR FORCE MATERIALS LABORATORY. The rear view of the panel shows the location of the controller and its related parts. For a complete description of the controller and its wide field of capabilities a technical manual (TM-1014) has been attached for reference.

The three drive motors have been wired identically and a polarized plug is installed on each motor cord as shown in Figure 2. Connecting the plug from any one of the three vacuum test fixtures to the outlet receptacle on the front of the controller panel is all that is necessary to activate it for controlled rotary motion. The following procedures should be used to assure proper operation.

- (1) Begin with the MOTOR START/STOP SWITCH in the OFF position.
- (2) Turn the SPEED CONTROL digital readout to zero.
- (3) Turn the 110V LINE SWITCH. The red PILOT LIGHT should come on. A high-pitched whine will be heard at this time; this is normal.
- (4) Move the MOTOR START/STOP SWITCH to ON.

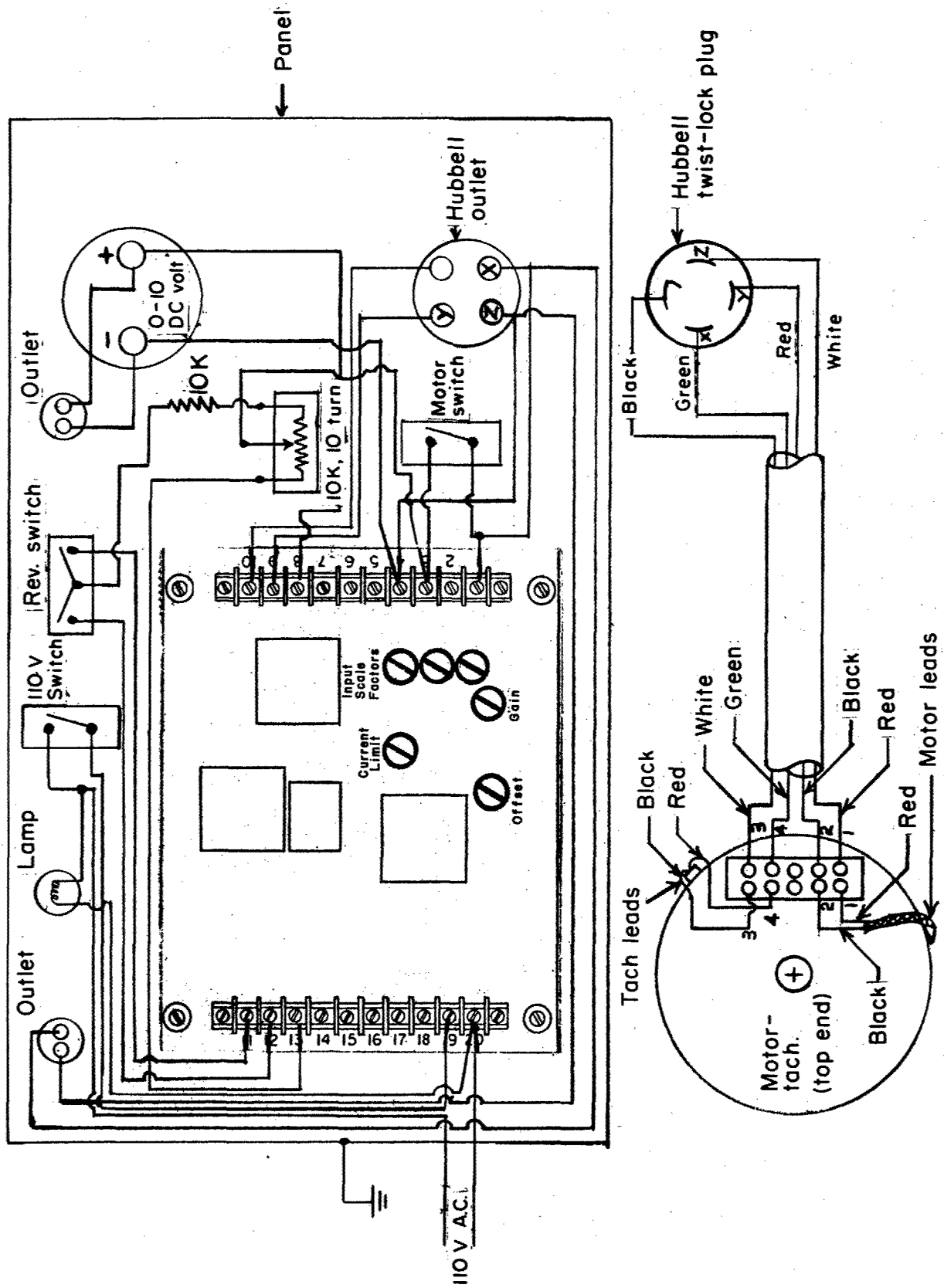


FIGURE 2. MOTOR CONTROL PANEL WIRING DIAGRAM

- (5) Increase the SPEED CONTROL from zero. The motor should now be rotating. If it is not turning in the desired direction, it can be reversed by changing the FWD/REV switch. This should be done at zero speed. By increasing the SPEED CONTROL to 999, a maximum motor speed of 400 rpm will be attained. (This maximum speed setting can be adjusted by the INPUT SCALE FACTOR adjustment on the back of the controller as described in the attached TECHNICAL MANUAL.)
- (6) Motor current is monitored with the MOTOR CURRENT INDICATOR on the panel. This is a voltmeter which indicates current at 2 amps/volt. In this case the CURRENT LIMIT on the back of the controller has been set at 4 amps (2 volts). The fuse will blow at 5 amps. The voltage signal can also be monitored on an oscilloscope for greater sensitivity. To do this connection should be made to the CURRENT MONITOR OUTPUT plug. Caution: Do not ground either lead of this plug. A nongrounded scope circuit must also be used.
- (7) A TACHOMETER OUTPUT has also been provided. A voltmeter can be connected to this terminal and calibrated to read directly in rpm.

Other Considerations

This motor and control system can be operated continuously at any set speed from below 10 to above 1800 rpm. The motor can be operated in either direction. The arrow on the bottom of the motor housing was used in the manufacturing process and should be disregarded during operation. These motors may also be operated in any position.

TM-1014

TECHNICAL MANUAL

MODEL NC102

SOLID STATE DC SERVO CONTROLLER

1.0 DESCRIPTION

The Model NC102 is a completely self-contained, solid state transistorized DC servo controller intended for application in closed loop servo systems employing DC servo motors. Due to the versatility and flexibility of the Model NC102, both position and velocity control systems can be instrumented with little or no external equipment. In closed loop numerically controller or computer controlled systems, the NC102 can accept the output directly from a D to A converter, and provide all the required amplification and compensation for completing a high performance servo loop.

The controller is totally contained in a modular assembly which is designed to mount directly to existing chassis or sub-panels. All adjustments for gain, scale factor, current limit, etc. are contained on the printed circuit board and are accessible from the top of the controller. No critical adjustments for over-lap, bias or firing circuit control are required. The basic module contains, in addition to the controller electronics, an isolation transformer, power supply and heat sinking for the power output semiconductors.

Since each controller is pretested and operated at rated loads for 40 hours, initial turn-on problems are virtually eliminated. The result of this extensive testing, coupled with an in-process quality assurance program, assures long-term maintenance-free operation of each controller.

Complete closed loop servo systems can be easily constructed using the Model NC102 servo controller, since the unit contains a preamplifier with adjustable gain and damping controls. The three adjustable gain inputs can be employed to sum the outputs of feedback transducers, computer outputs, and the outputs from process controllers or other control instrumentation.

Unless otherwise specified, temperature at 25° centigrade and line voltage at 117VAC.

2.0 DETAILED SPECIFICATIONS

- | | |
|-------------------------------------|---|
| 1. INPUT POWER | 107 to 125VAC, single phase, 50 to 400Hz |
| 2. TYPE OF CONTROL | Regenerative, four quadrant reversing for DC servo motors |
| 3. CURRENT RATING | |
| (A) PEAK (1 SECOND) | 24 amps |
| (B) RMS | 5 amps |
| (C) AVERAGE (CONTINUOUS) | 5 amps |
| 4. MAXIMUM OUTPUT VOLTAGE (NO LOAD) | ± 60 VDC |
| 5. CURRENT LIMIT RANGE | |
| (A) INTERNAL POTENTIOMETER CONTROL | ± 6 to ± 24 amps |
| (B) EXTERNAL POTENTIOMETER | 0 to ± 24 amps |

6.	FREQUENCY RESPONSE	DC to 1000Hz
7.	NUMBER OF SIGNAL INPUTS	Three (3)
8.	INPUT IMPEDANCE	
	(A) INPUT 1	6K min.
	(B) INPUT 2	8K min.
	(C) INPUT 3	10K min.
9.	GAIN OF PREAMPLIFIER (can be changed by resistor selection)	
	(A) INPUT 1	250 - 2500 volts/volt
	(B) INPUT 2	125 - 1250 volts/volt
	(C) INPUT 3	62 - 620 volts/volt
10.	GAIN OF POWER AMPLIFIER	2.4 amps/volt, $\pm 10\%$
11.	GAIN LINEARITY (combined power amplifier and preamplifier)	$\pm 2\%$
12.	GAIN STABILITY (combined power amplifier and preamplifier)	$\pm 2\%$
13.	COOLING	Convection
14.	TEMPERATURE RISE AT FULL RMS OUTPUT	45°C with cooling fins mounted vertical 50°C with cooling fins mounted horizontal
15.	AMBIENT TEMPERATURE RANGE	
	(A) OPERATING	0 to 50°C
	(B) STORAGE	-30 to +65°C

16. OFFSET	Adjustable to zero by internal potentiometer
17. DRIFT (REFERRED TO INPUT)	Less than 20 microvolts per degree centigrade
18. CURRENT FORM FACTOR	1.01 max., 30 to 100% output
19. AUXILIARY POWER OUTPUT	
(A) Regulated +15VDC	15VDC, 1.5V, 10ma maximum
(B) REGULATED -15VDC	15VDC, $\pm 1.5V$, 10ma maximum
(C) NONREGULATED OUTPUT	+52VDC, +15%, -30% depending on line voltage and controller output current. 0.5 amps maximum.
(D) REGULATION RIPPLE	Regulated outputs have combined line, load regulation and ripple of $\pm 1\%$
20. AUXILIARY CONTROL INPUTS	
(A) REMOTE ON/OFF	Contact closure for "off"
(B) POSITIVE ON/OFF	Contact closure for positive drive "off"
(C) NEGATIVE ON/OFF	Contact closure for negative drive "off"
21. PROTECTION	Current limit, line and load fuses
22. ISOLATION	Integral transformer provides isolation from line and signal common.

3.0 TERMINAL CONNECTIONS AND DESCRIPTIONS

The following section describes the location and function of each terminal connection and describes certain important characteristics pertaining to the input or output. In many cases, the flexibility of the NC102 controller permits utilization of control techniques that are unique to a given application. In reading the various descriptions of the terminal connections, many applications and utilizations will become self-evident.

TERMINAL

FUNCTIONAL DESCRIPTION

- | | |
|---|--|
| 1 | <u>Signal Input Number 1</u> - The scale factor is adjustable by INPUT SCALE FACTOR potentiometer 1. Input impedance is 6K min., and the scale factor is adjustable over a 10:1 range. |
| 2 | <u>Signal Input Number 2</u> - Same characteristics as Terminal 1, but adjustable by the potentiometer marked INPUT SCALE FACTOR 2. Input impedance is 8K min. |
| 3 | <u>Signal Input Number 3</u> - Same characteristics as Terminal 1, but adjustable by the potentiometer marked INPUT SCALE FACTOR 3. Input impedance is 10K min. |
| 4 | <u>Signal Common</u> - Common for all signal inputs and signal outputs with the <u>exception of the high current motor outputs</u> . This common is isolated from power line common. |

TERMINAL

FUNCTIONAL DESCRIPTION

5 and 6

External Current Limit Control - External control of current limit can be implemented by connecting an external potentiometer from Terminal 5 to common (Terminal 4) and connecting the wiper to Terminal 6. The potentiometer will provide current limit control from 0 to 24 amps. Note: The internal current limit potentiometer should be set full CCW when employing an external potentiometer. When not employing external current limit control, terminals 5 and 6 must be shorted together.

7

Remote On/Off Control - The controller can be remotely turned OFF by connecting Terminal 7 to common (Terminal 4). Maximum voltage at Terminal 7 is 10 volts and the current does not exceed 5ma when shorted to common.

8

Current Monitor Output - The voltage on Terminal 8 with respect to Terminal 4 is proportional to actual motor current with a scale factor of 0.25 volts/amp of motor current. The full range of the current monitor output is ± 6 volts corresponding to the maximum motor current of 24 amps. This signal is intended to be used for driving meters or other measuring equipment.

TERMINAL

FUNCTIONAL DESCRIPTION

9 and 10

Controller Output - The motor is connected directly to terminals 9 and 10. The polarities are such that a positive signal input on either terminals 1, 2 or 3 will produce a positive output on terminal 10 with respect to terminal 9.

CAUTION: DO NOT SHORT EITHER OUTPUT TERMINAL TO COMMON AS THIS COULD RESULT IN DAMAGE TO THE POWER AMPLIFIER SECTION.

11

+15VDC Output - A source of +15VDC at 10ma is available on terminal 11. The combined line and load regulation and ripple is less than $\pm 1\%$. The actual DC value of the output is between 14 and 16.5VDC.

12

-15VDC Output - A source of -15VDC at 10ma is available on terminal 12. The combined line and load regulation and ripple is less than $\pm 1\%$. The actual DC value of the output is between 14 and 16.5VDC.

13

Auxiliary Output Common - Common connection for the ± 15 VDC outputs and the +52VDC output.
Terminal 13 is internally connected to Terminal 4.

TERMINAL

FUNCTIONAL DESCRIPTION

- 14 Auxiliary Output - Terminal 14 provides a source of non-regulated +36VDC, for driving external relays or other control equipment. Accuracy is +15% to -30% depending on conditions of line input and load current. Maximum current drain should be less than 0.5 amps.
- 15 and 16 Negative Off - A contact closure between terminals 15 and 16 will limit the output of the controller in the negative direction. These terminals are intended to be employed with limit switches to prevent the controller from driving a motor into an extreme travel stop.
- 17 and 18 Positive Off - Same function as terminals 15 and 16, but limits the output of the controller in the positive direction.
- 19 and 20 115VAC Input - Single phase, 107 to 125VAC, 50-400Hz is applied to these terminals. Service to the controller should be rated at 15 amps.

4.0 DETAILED DESCRIPTION

4.1 Preamplifier Description

As shown in the functional schematic, the preamplifier employed in the Model NC102 servo controller is of the operational amplifier type with an integral, adjustable servo compensation network. The three adjustable inputs can be employed directly to form the summation of command and feedback signals, with scale factors determined by the internal potentiometer settings.

The preamplifier is provided with a variable servo compensation network that can be adjusted to provide optimum performance with most velocity type servos and position servos employing tachometer rate feedback. The basic compensation network provides a high DC gain for excellent low speed performance in addition to a variable lag-lead network which can be adjusted to accommodate various types of motors, tachometers, and inertial loading. The compensation elements are mounted on solder terminals and can be easily changed to accommodate applications requiring special compensation networks.

The actual transfer function and associated frequency response of the preamplifier and compensation network is shown in A599-0003. With the gain potentiometer turned full CW, all lag-lead compensation is removed and the amplifier response is flat to 1000Hz where the input filter begins to attenuate the signal input. When the gain potentiometer is

turned full CCW, the compensation provides a lag at 4 radians per second and a lead at 180 radians per second. Turning the gain potentiometer toward the CCW position lowers the break frequency of the lag network, but maintains constant DC gain.

In addition to the variable compensation, the input scale factor of each input can be adjusted over a 10:1 range which can be employed to vary the actual value of DC gain.

Due to the extremely high frequency response of the NC102 and the adjustable compensation network, servo bandwidths can be set from 30 to 500CPS. In addition, load inertias varying from $0.003 \text{ oz-in-sec}^2$ to 0.10 oz-in-sec^2 can be stabilized with the adjustments provided. The factory should be consulted if the load exceeds an inertia of greater than 0.10 oz-in-sec^2 .

4.2 Power Amplifier Description

The power stage of the Model NC102 controller is a full four quadrant, reversing regenerative transistorized power amplifier. The amplifier employs a high efficiency switching mode technique which is capable of delivering power to the motor in normal operation and also removing power from the motor during periods of reversals. An extremely high response is obtained since the amplifier is configured in a current drive configuration. This technique eliminates variations in gain and scale factor due to various armature resistances and heating or armature resistances. In addition, the current mode configuration reduces the L/R time constant of the motor by factors of 10 or more over the normal L/R time constant listed for any particular motor.

A current limit circuit is employed within the power amplifier which automatically limits motor current to a predetermined level even during periods of high speed reversals or short circuits. It should be noted that the transistor switching amplifier employed in the Model NC102 controller operates at a frequency of approximately 7-15KHz. This high frequency achieves a usable bandwidth beyond 1KHz and therefore does not limit servo response as conventional SCR type amplifiers do.

In contrast to more conventional transistor type amplifiers, the power amplifier employed in the Model NC102 controller achieves an efficiency

of greater than 87% for any level of output power. Conventional transistor amplifiers typically operate at efficiencies in the neighborhood of 30 to 60% depending upon conditions of motor back EMF and armature resistance. By virtue of the unique switching type amplifier employed (patent applied for) the Model NC102 controller can operate efficiently with virtually any type of DC motor, including the low resistance, high response type moving coil motors. Operation of the controller is in no way impaired by low armature resistances or motors exhibiting high back EMF constants. Typical range of motor resistances can vary from below a tenth of an ohm to greater than five ohms with no degradation of amplifier performance.

5.0 ADJUSTMENTS

The Model NC102 Servo Controller is shipped from the factory completely checked and run at full load conditions. The only adjustments required are those which adapt the parameters of the controller to the specific application. These adjustments include:

- (1) Scale Factor (gain) of each input
- (2) Current Limit adjustment
- (3) Servo Gain (stability) adjustment
- (4) Offset adjustment.

In each case, the adjustments can be simply made by either observing the performance of the servo with an oscilloscope or by visual observation. No special tools or test equipment is required to make any of the adjustments. The following procedures are recommended as an outline to making the optimum controller adjustments.

5.1 Scale Factor Adjustments

Three scale factor potentiometers are included and are labelled 1, 2 and 3 which correspond to inputs 1, 2 and 3. In each case, the potentiometers form an attenuator across the indicated input which provides attenuation from approximately 1:1 to 10:1. Increasing rotation toward the CCW provides increased attenuation. The primary function of the scale factor adjustments is to provide an adjustment between each of the three inputs so that the outputs of various feedback transducers can be matched to the input command signal.

5.2 Current Limit Adjustment

The current limit adjustment provides control over the maximum current allowed to flow in the motor even under cases of plugging and short circuits.

The total range of the internal current limit potentiometer corresponds to a current limiting range of 6 amps to 24 amps. Full CCW rotation of the current limit potentiometer corresponds to 24 amps.

Current limit can be controlled externally by removing the jumper between terminals 5 and 6 and placing a 5K potentiometer as shown in C599-0001. When using an external current limit potentiometer, the internal current limit potentiometer should be set to the full CCW position. The range of current limit for the external potentiometer is from 0 to 24 amps.

When setting the current limit (either by internal or external potentiometer), a signal proportional to actual load current can be monitored on Pin 8 with respect to Pin 4 (common). The scaling is such that each volt corresponds to 2 amps of load current. The most straight-forward technique in setting the limit to any desired value is to first start with the minimum value (internal potentiometer full CW) and observe the current monitor with an oscilloscope during the motor acceleration. Increase the potentiometer until the value of current limit is achieved.

5.3 Servo Gain (Stability) Adjustment

The servo gain can be easily adjusted by simply monitoring the feedback transducer output while applying square wave input. Adjust the gain potentiometer for minimum over-shoot and most rapid response. In general, low inertia loads require that the gain potentiometer be set near the CCW position while high inertia loads require a setting nearer to the full CW position. The broad range of adjustment provided in the Model NC102 controller usually will operate with virtually any rate or rate stabilized position servo loop. However, in certain cases, extreme structural or mechanical resonances require special compensation techniques. In these cases, the detailed servo analysis must be performed. Control Systems Research, Inc. maintains a full staff of servo design specialists who would be happy to discuss your specific application and recommend a special compensation technique.

5.4 Offset Adjustment

An offset control is provided for adjustment of any unbalance present in either the preamplifier or power amplifier. Adjustment can be made simply by first removing all input signals and connecting the output to the intended motor load. Apply the 115VAC input, and adjust the offset potentiometer until the motor stops rotation.

If a more precise adjustment is required, place a voltmeter (VOM type) across terminals 8 and 4 and adjust the offset potentiometer until the voltage reads zero (or as near as possible).

The offset adjustment can be also employed to remove small offsets in the input signal.

6.0 CALCULATION OF RMS CURRENT

Since the Model NC102 servo controller is rated to drive peak loads which are greater than the RMS rating, the following analysis is included to provide a procedure for actual RMS current calculation. It should be noted that although the controller is rated at 7 amps RMS, protection is included which prohibits damage should this rating be exceeded.

In establishing the actual RMS current, a knowledge of the current waveform must be either known or measured in actual operation. Measuring the instantaneous current is easily accomplished by connecting an oscilloscope between terminal 8 and terminal 4 (common). The voltage output of this signal is directly proportional to load current and is scaled at 0.25 volts per amp of load current.

Since the RMS current is defined as:

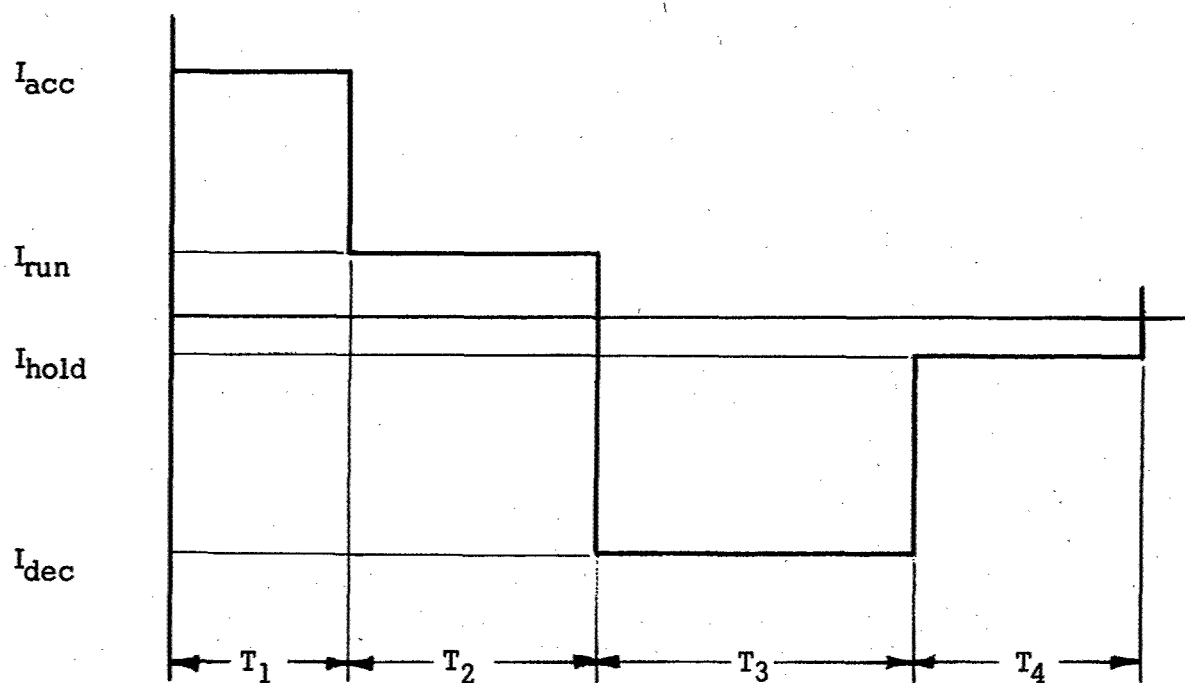
$$I_{RMS} = \sqrt{\frac{1}{T} \int_0^T I^2 dt}$$

A complete RMS calculation would require the evaluation of integrals.

However, in virtually all applications, the current waveform can be divided into four separate areas, namely:

- (1) acceleration current
- (2) running current
- (3) deceleration current
- (4) holding or friction current

In a typical application, the motor current waveform would appear to be like that shown in Figure 3.



$$\text{CYCLE TIME} = T_5 = T_1 + T_2 + T_3 + T_4$$

FIGURE 3

Typical Current Waveform For A Position or Rate Servo Application

With the waveform of Figure 1, the RMS current can be easily calculated by:

$$I_{RMS} = \sqrt{\frac{1}{T_5} \left[I_{acc}^2 T_1 + I_{run}^2 T_2 + I_{dec}^2 T_3 + I_{hold}^2 T_4 \right]}$$

As an example of the use of Equation 1 is illustrated by considering a typical positioning application. In this actual application, a mass was positioned intermittently at a rate not exceeding one cycle per second. The currents and times were established as follow:

$$I_{acc} = 24 \text{ amps for } 0.020 \text{ sec.}$$

$$I_{run} = 4 \text{ amps for } 0.210 \text{ sec.}$$

$$I_{dec} = 24 \text{ amps for } 0.020 \text{ sec.}$$

$$I_{hold} = 3 \text{ amps for } 0.75 \text{ sec.}$$

$$I_{RMS} = \sqrt{(576)(.020) + (16)(.210) + (576)(.020) + (9)(.75)}$$

$$I_{RMS} = 5.8 \text{ amps}$$

$$I_{avg} = (24)(.020) + (4)(.210) + (24)(.020) + (3)(.75)$$

$$I_{avg} = 4.02$$

The Model NC102 servo controller is rated at an average current of 5 amps and RMS current of 7 amps which satisfies both requirements.

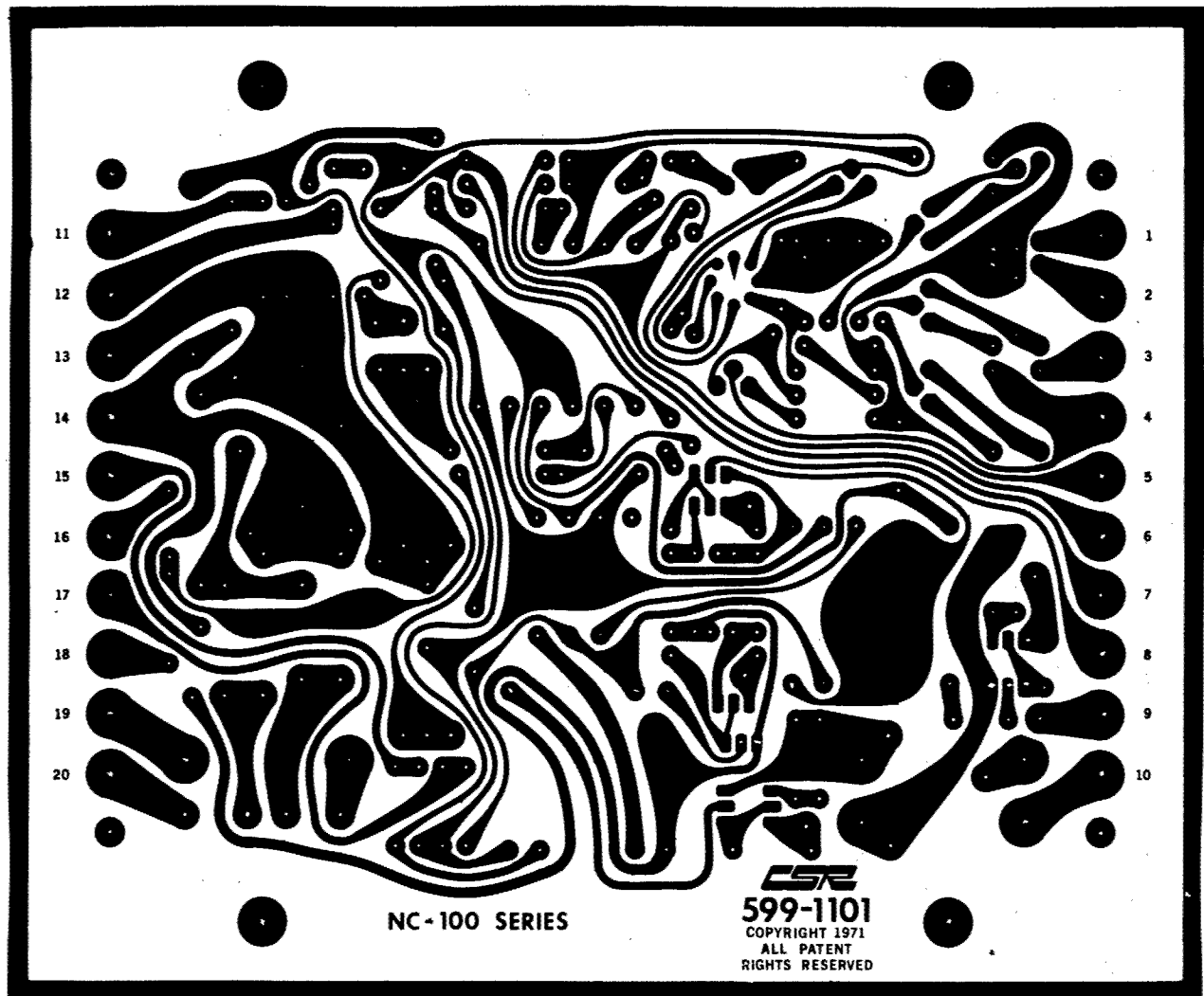


FIGURE 4
PRINTED CIRCUIT LAYOUT - NC100 SERIES CONTROLLER

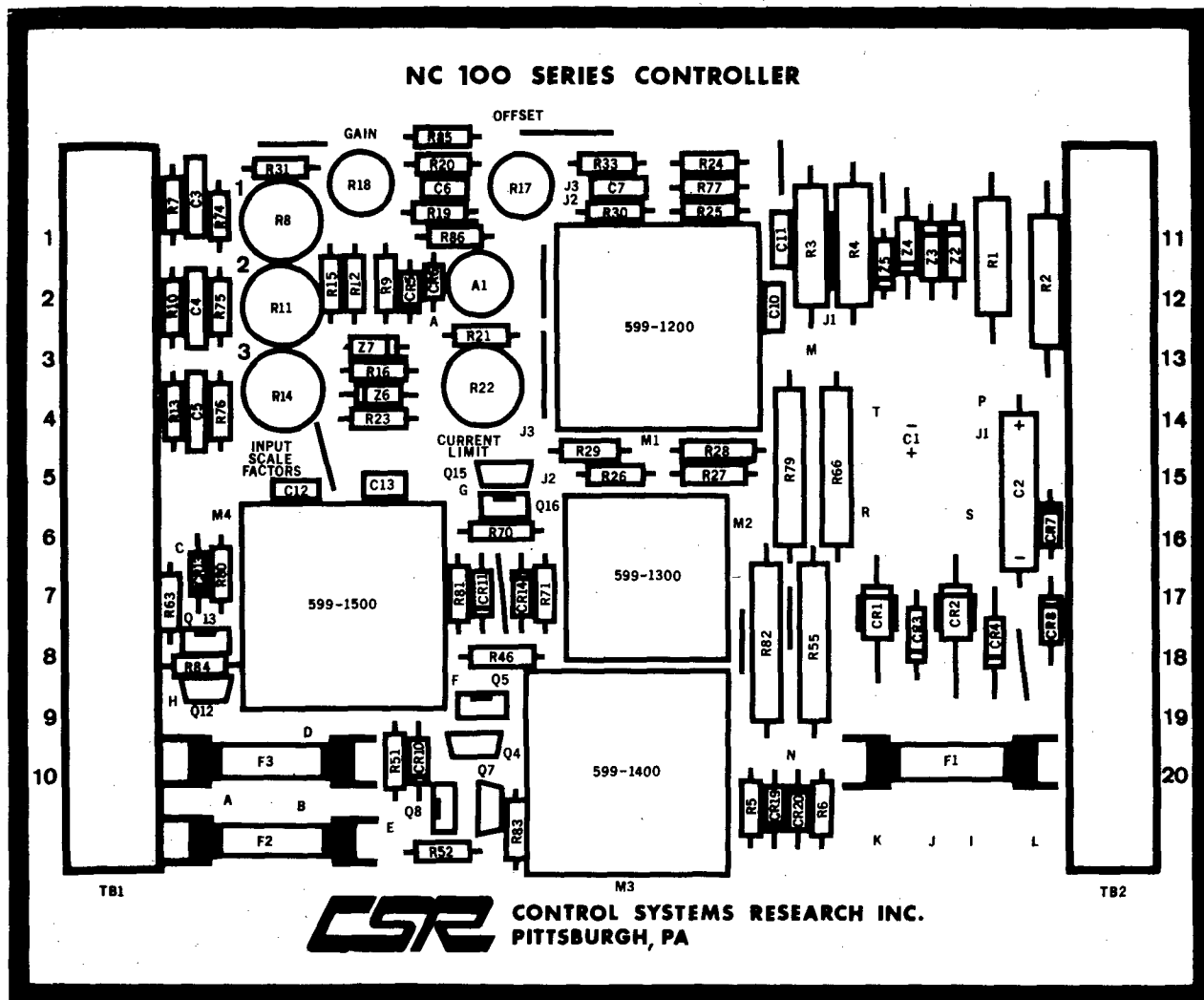
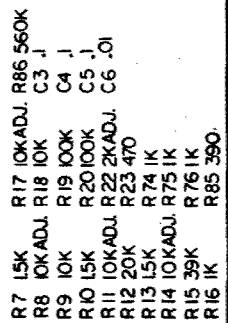


FIGURE 5
DETAILED COMPONENT LAYOUT - NC100 SERIES CONTROLLER

FIGURE 6

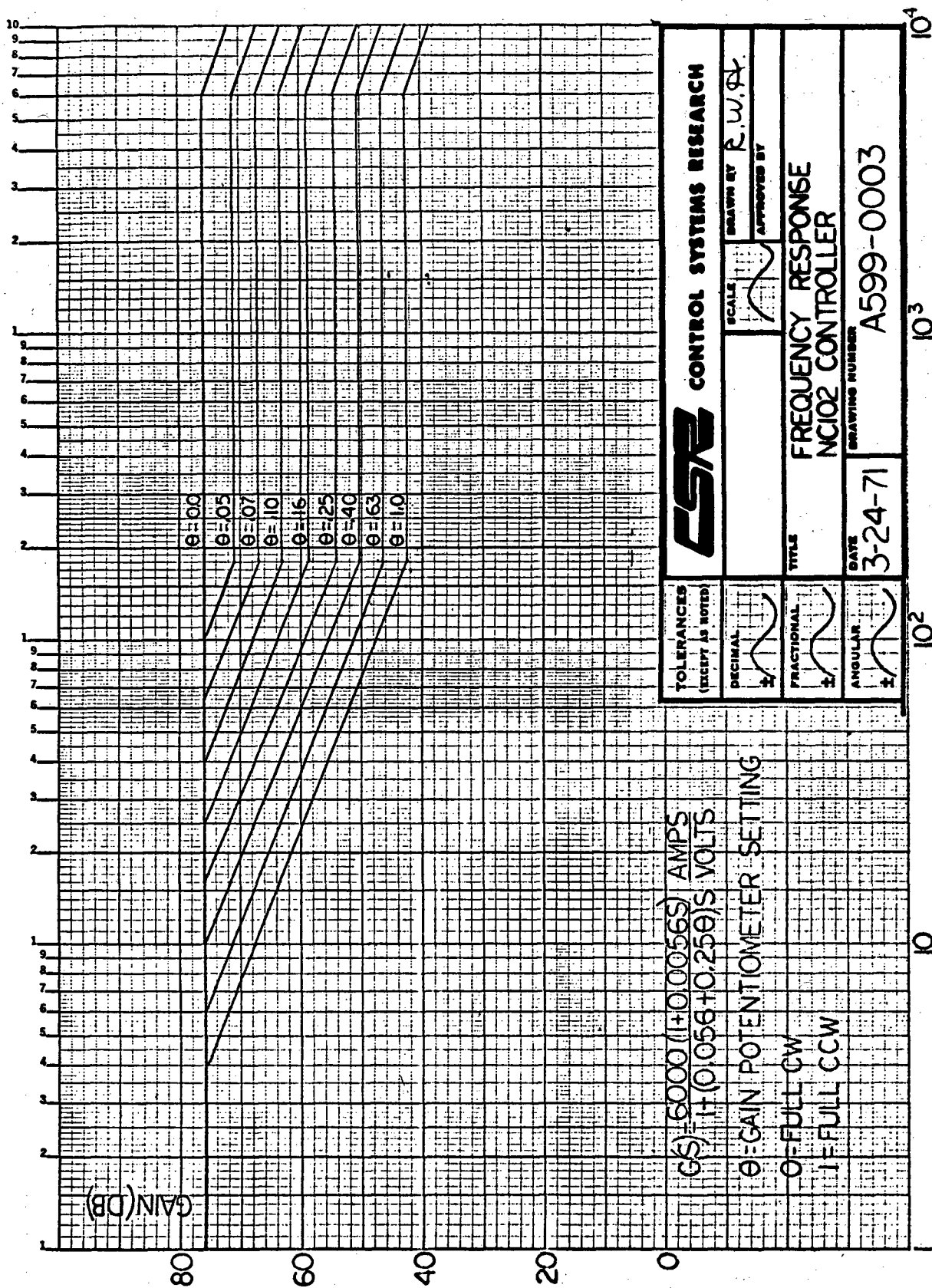
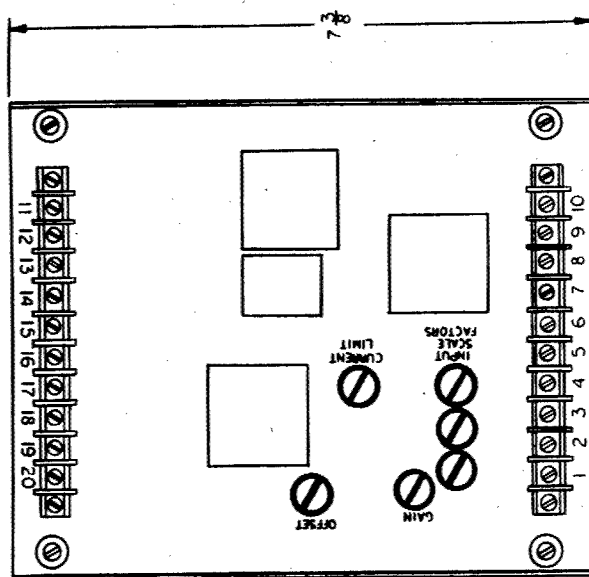
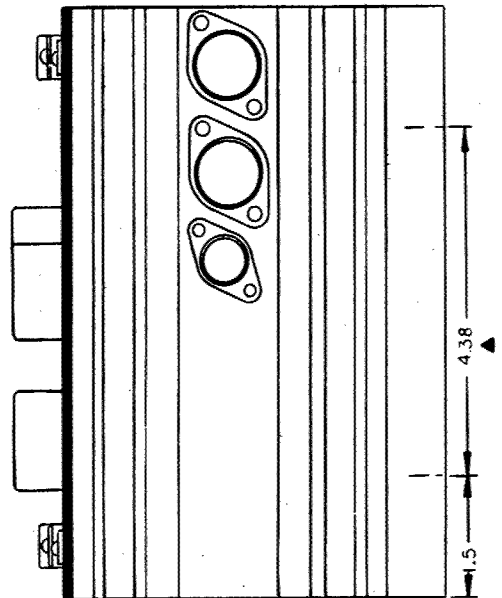
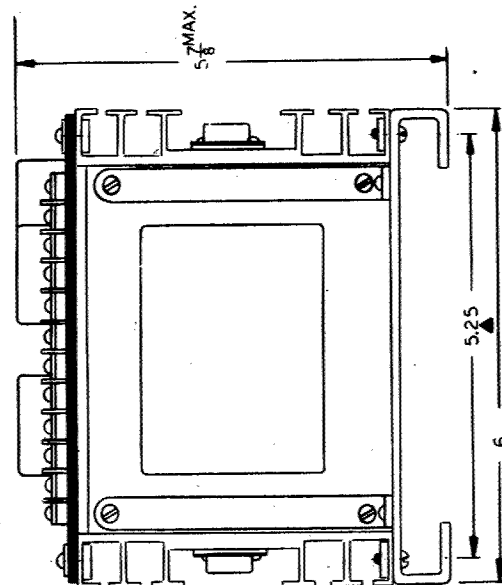


FIGURE 7



FINISH: --- BLUE ANODIZE
 ▲ MOUNTING --- 1/4 - 20 NC-2 --- (4) PLACES



CONTROL SYSTEMS RESEARCH			
MODEL	NC100 SERIES	DESIGNED BY	J.R.
REV.	1 TO 1	DESIGNED BY	R.G.B.
ENCLOSURE OUTLINE			
HIGH RESPONSE INDUSTRIAL DRIVE			
DATE	10-15-70	PROJECT NO.	599-0000
DRAWN BY	J.R.	CHECKED BY	J.R.
APPROVED BY	J.R.	DATE	10-15-70
SCALE	1" = 1"	ASSEMBLY	0' 30"

FIGURE 8

APPENDIX II

INSTRUCTION MANUAL

for

ASSEMBLY, CALIBRATION, AND OPERATION OF BEARING TEST EQUIPMENT LUBRICATION DEGRADATION RIG LUBRICANT DEWETTING RIG

INTRODUCTION

Two test fixtures have been designed and constructed: one for the purpose of studying life tests for lubricant degradation failure mechanisms, and the other for carrying out studies involving bearing surface dewetting phenomena. Experimental programs can be carried out with this equipment under conditions which simulate those applicable for mechanically despun antenna systems in space. This manual contains descriptions of assembly, calibration and operation procedures of all components. FIGURES 3, 4, and 5 illustrate the fixtures and associated instrumentation.

The apparatuses have been designed to permit the future use of thin-film vacuum-vapor-deposited pressure and temperature sensing elements. With this type of instrumentation, it is possible to monitor the contact load or temperatures developed between the rolling elements of the bearing and its races. Application of the transducer to the bearing surfaces can be done at BATTELLE'S COLUMBUS LABORATORIES. Installation of the instrumented bearing in the test fixture would be accomplished in the same manner described in this manual. Circuit recommendations and operation instructions would be furnished at time of transducer application.

GENERAL CONSIDERATIONS

This equipment has been designed and constructed with strict adherence to high standards in regard to high-vacuum welding techniques and precision machining methods. It is cautioned that care be given when working with these experimental fixtures to prevent degradation of original capabilities. All assembly work should be carried out under clean laboratory conditions. Internal parts should be handled while wearing white gloves. All tools and other equipment used in this work must be free of burrs, rust, dirt and oil.

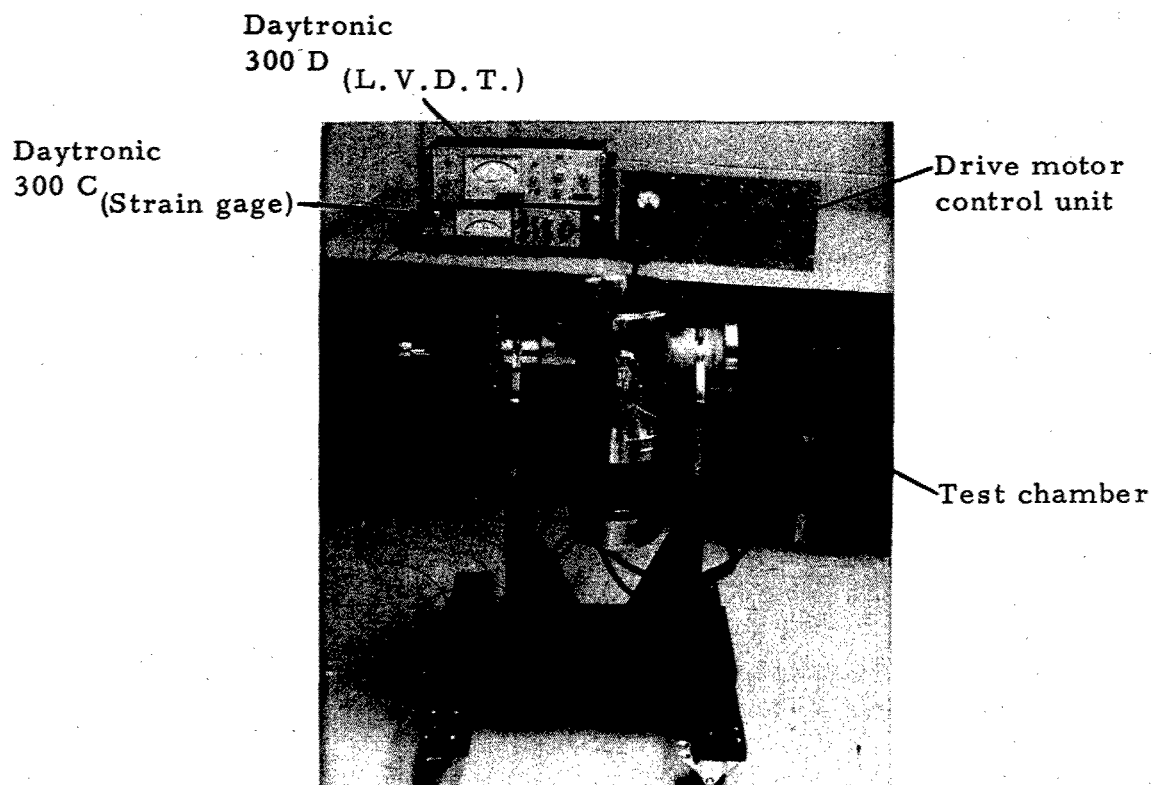


FIGURE 3. BEARING FIXTURE WITH INSTRUMENTATION

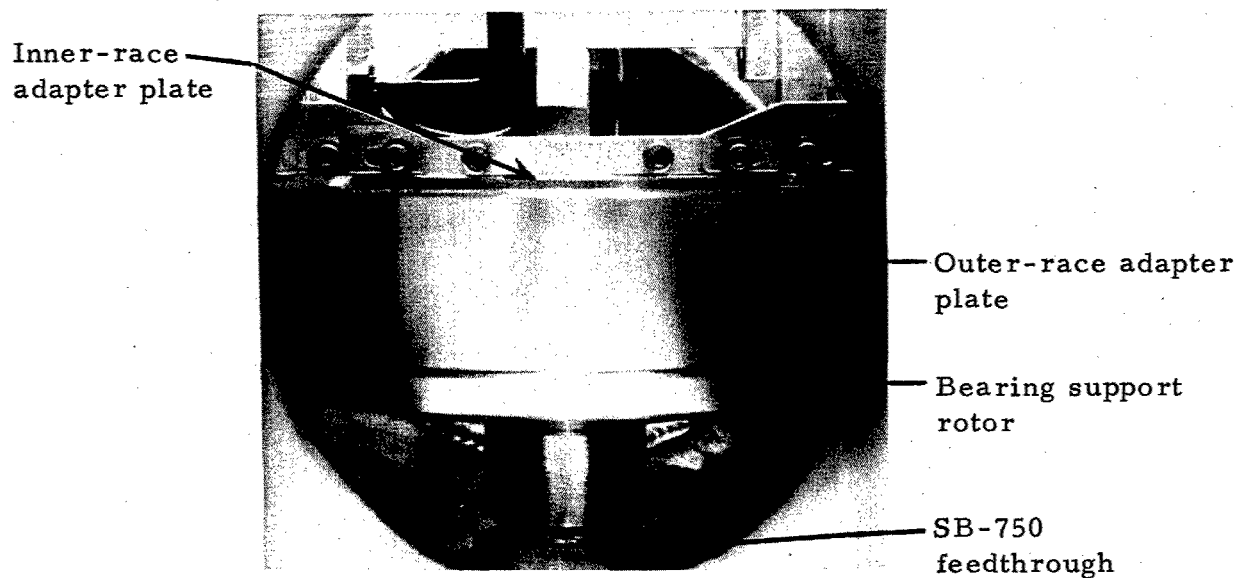


FIGURE 9. VIEW THROUGH 6-INCH PUMPING PORT

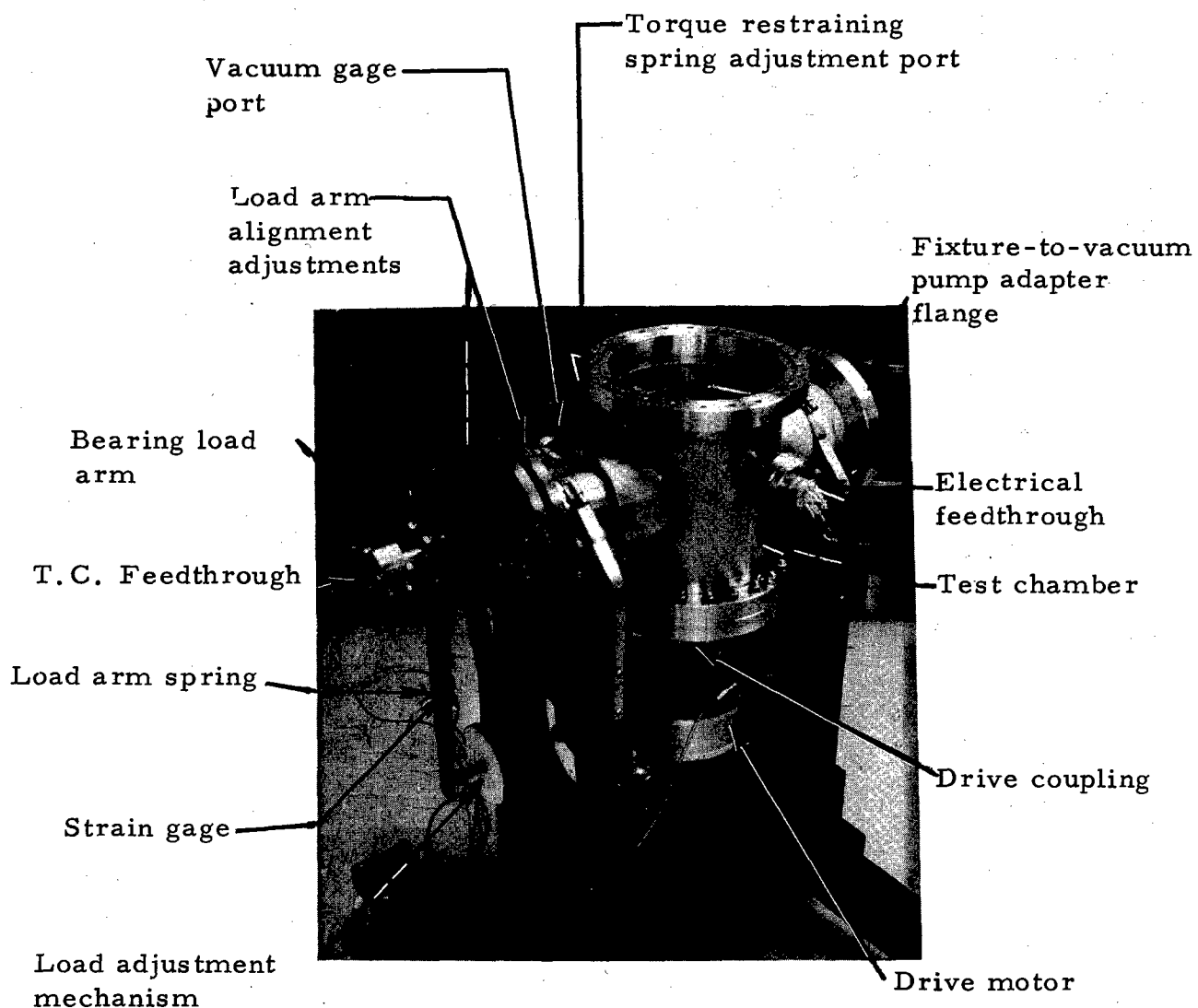


FIGURE 10. BEARING VACUUM APPLICATION TEST FIXTURE

When assembling any high vacuum system, it is always of utmost importance that all parts be cleaned and inspected. The procedure used during construction of these fixtures consisted first of cleaning all parts (except the test bearing) in hot water and detergent followed by a cold water rinse. This was followed with a wash in acetone and a final rinse with 200-proof alcohol.

Parts should be dried and installed in the test chamber as soon as possible. All vacuum sealing surfaces must be protected to prevent damage from occurring while work is being done. All copper gaskets should be inspected for flaws or damage that would prevent proper sealing. Extreme care must be exercised to assure proper alignment of gaskets to their mating surfaces. Threaded areas of all flange bolts should be coated with an anti-seize compound such as FEL-PRO C5-A. Flange bolts must be tightened evenly to assure uniform compression and positive sealing.

ASSEMBLY PROCEDURES

Installation of Test Bearing

For each size bearing that is to be tested, a set of inner and outer bearing adapter plates will have to be designed and fabricated. When designing these different plates it is necessary to retain the originally designed total thickness so as to insure the proper operation of the axial loading mechanism. Sufficient space has been provided to accommodate the extra thickness of the largest bearing possible for the test fixture.

The bearings supplied with the fixtures are FAFNIR superprecision 2MM9118W1-CR. The adapter plates have been individually matched to the respective bearing dimensions for each rig. A light machine press fit has been used in all cases for the parts involved in mounting the bearing on the feedthrough shaft. To remove the adapter plates from a bearing it is necessary to use the three threaded holes provided in each plate. By installing screws in these holes the bearing and its plates can be forced apart.

After assembling the plates on a test bearing, the unit is carefully installed on the bearing support rotor. Again, a close fit has been provided between the outer-race adapter plate and the rotor (Ref. FIGURE 4). Four socket-head screws are used to hold the plate in position and these can be installed from above through an access hole in the inner race adapter plate. A special dummy rotor fixture has been supplied for use in making additional outer-race adapter plates (for other bearing sizes). Use of this fixture will assure proper alignment and minimum runout of any plate fabricated.

Assembly and Alignment of Loading System

The bearing loading plate is positioned over the outer end of the load arm extension. A straightened length of 35 mil (0.9 mm) music wire is placed in the clamp of the extension arm. A 90° bend is used on the end of the wire and inserted into the clamp groove parallel to the locking bolt. This facilitates alignment and gives more holding power to the clamp. The wire should rest in the vertical grooves of the extension arm and the clamping plate when properly assembled. The wire should also be allowed to protrude upward through the loading plate. Now position the load-arm extension in the fixture. By turning it sideways and carefully maneuvering the end of the arm with the wire clamp, this will slip into the hole in the center of the inner-race adapter-plate. At this point the extension arm is placed in its proper position and the two mounting screws that hold it to the load arm can be installed. The ceramic insulating blocks and the clamping bar can now be placed on the BEARING LOADING PLATE as illustrated in FIGURE 6. The load arm extension should be lowered to a point where the music wire is centered and vertical, and the upper wire clamp tightened. Make certain the wire is positioned in the grooves of the ceramic blocks. (The pressure may crack the blocks but this will not impair their holding action.) If the wire is not aligned with the center line of the bearing, the exterior end of the load arm can be adjusted by loosening the six bolts on the load arm clamp and sliding the arm in or out. The four load arm support bolts and brass stop screws may also be adjusted for side to side alignment. Once the load wire has been installed in the clamps of the load arm and bearing load plate, it is not necessary to disassemble the combination unless a new wire is to be installed. Once clamped the assembly can be removed and replaced without further adjustments.

Installation of Torque Measuring System

As shown in FIGURE 6, the TRANSDUCERS are mounted on a common SUPPORT BAR. This bar and its components should be assembled outside the FIXTURE using the following steps.

- a. Install the LEAD SUPPORT CROSSOVER consisting of glass tubing and end plates. Center and lock in place using the two setscrews.
- b. Mount the TRANSDUCERS in their BRACKETS and attach these to the SUPPORT BAR as shown. The bracket arms have been slotted to permit transducer alignment. The bracket and clamping bolts should be left loose at this time.
- c. The lead wires from the LEFT SIDE TRANSDUCER can now be placed through the wire support. Wires are bare copper and must not touch each other or short to ground.
- d. Install the SUPPORT (bar end) BRACKETS, these are left and right parts.

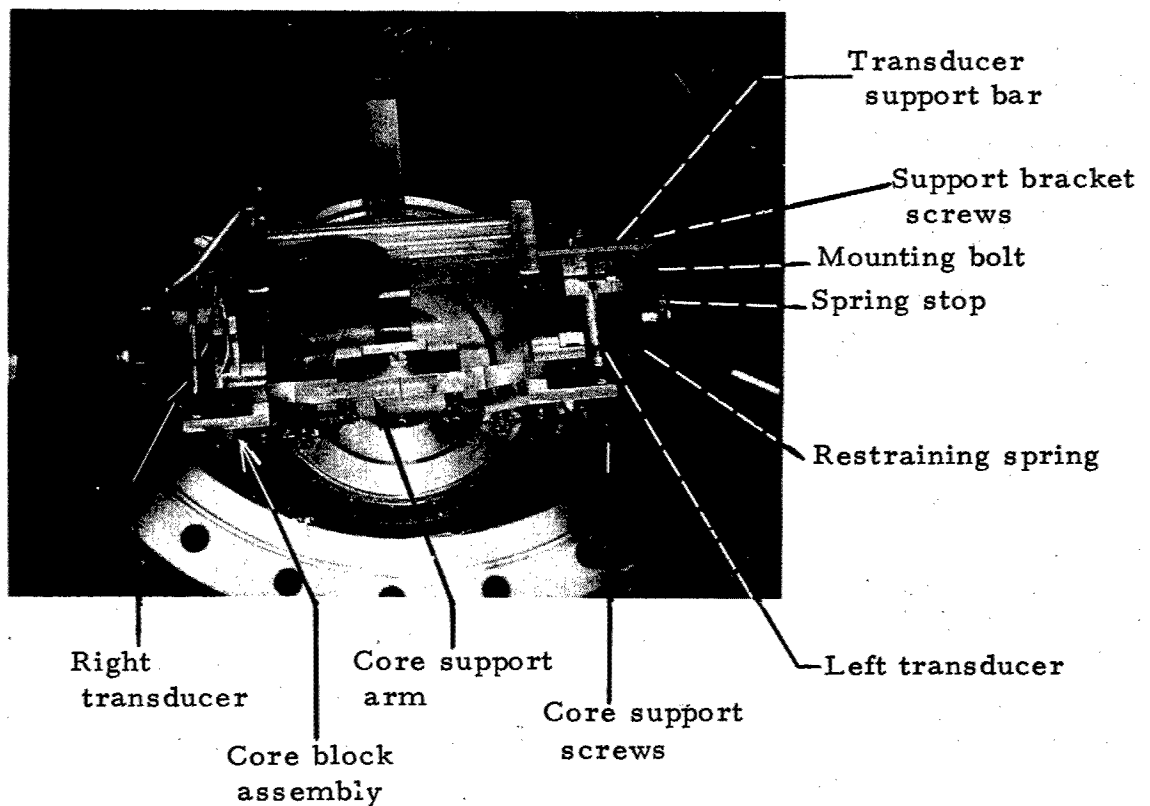
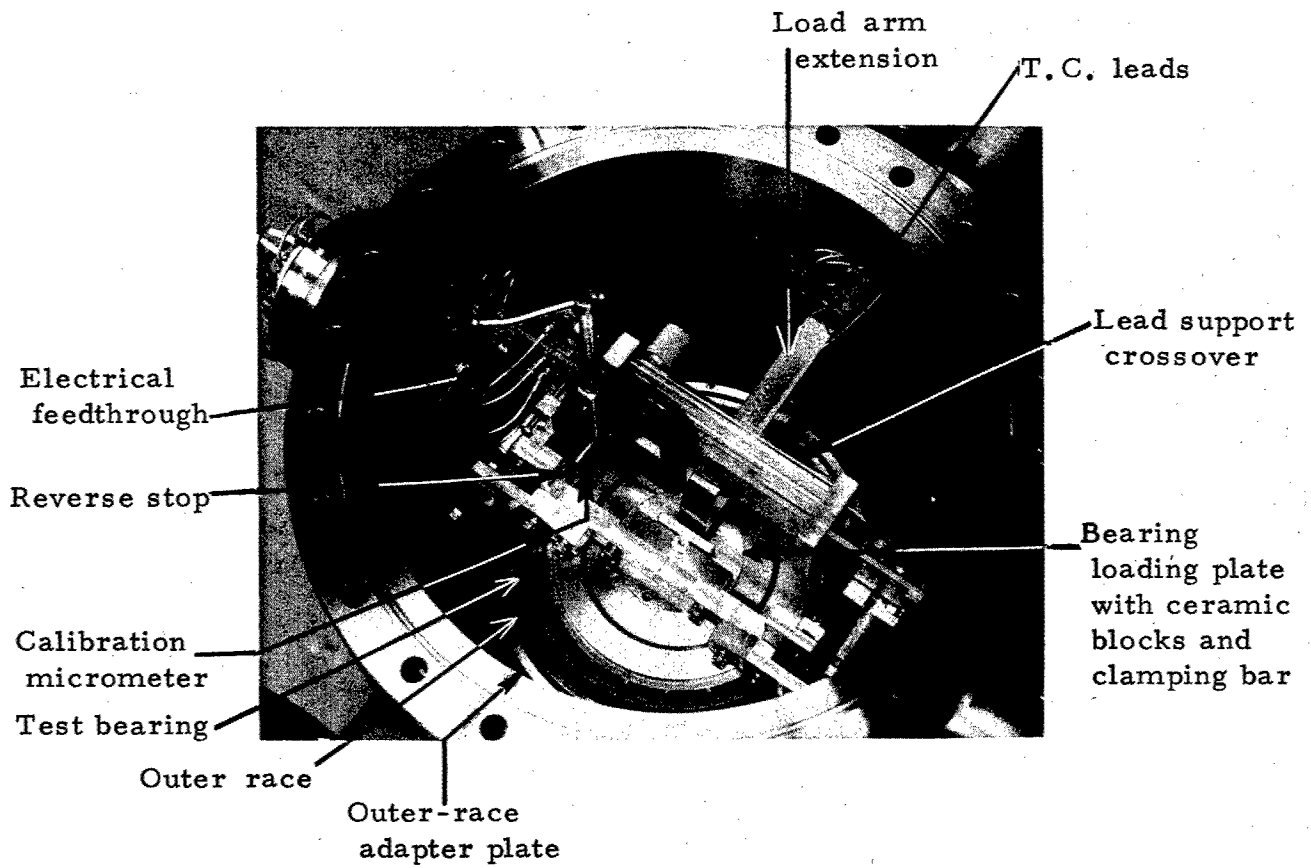


FIGURE 11 BEARING TORQUE MEASURING SYSTEM

The bar assembly is now placed in the FIXTURE and locked into position using two socket-head screws which attach the bar to the mounts in the one and one-half inch diameter tubing parts on opposite sides of the chamber. The TRANSDUCERS must be equally spaced from the center line of the bearing and have adequate clearance between the bracket and the bearings. The TRANSDUCERS can be further positioned by sliding them back and forth in their clamps for adjustment of mechanical null points during calibration. The clamps have enough preload on the transducer to prevent them from moving while the bar assembly is removed from the fixture. (The bar must be removed in order to tighten the clamping screws.)

To remove the bar, it is necessary to remove the two mounting bolts and also to loosen the support bracket screws on one end of the bar only. After calibration, and with the assembly removed, the transducer clamping screws may be tightened and no further adjustment should be needed.

With the support bar assembly mounted in the FIXTURE, the transducer leads can be connected to the ELECTRICAL FEEDTHROUGH. Push-on type connectors have been provided and when removing the assembly, the connectors may be tagged for proper connection during reinstallation. Alternatively the wiring diagram shown in FIGURE 7 should be used.

The RESTRAINING (flat) SPRING should now be attached to the CORE SUPPORT ARM. Calibration of this spring was done at BATTELLE-COLUMBUS LABORATORIES outside the FIXTURE, using dead weights and a measuring microscope. FIGURE 8 gives the results of the calibration method used.

After calibration, the arm and spring assembly is installed in the FIXTURE as shown in FIGURE 6. The SPRING STOP has been adjusted to give a one inch active length. This adjustment can be made through the one and one-half inch diameter port on the left side of the chamber. Using an Allen wrench, the locking screw can be turned and the stop moved to the desired position. Since the spring contact on the stop is glass, care must be taken to prevent damage.

The CORE SUPPORT ASSEMBLY can now be attached to the arm, (Ref. FIGURE 6). By directing a beam of light into the core end of the TRANSDUCER and observing the other end with a small mirror, the core can be centered and aligned so as not to touch the inside of the transducer case throughout its total travel. The midpoints of the two cores should be on a single diameter line of the test bearing and each should be exactly 3 inches from its center.

With careful maneuvering the transducer CORE SUPPORT ARM and the TRANSDUCER SUPPORT BAR assembly can be separated and either or both may be removed or replaced as required. If individual core or coil mounts are loosened it will be necessary to readjust mechanical null or to align parts during reassembly.

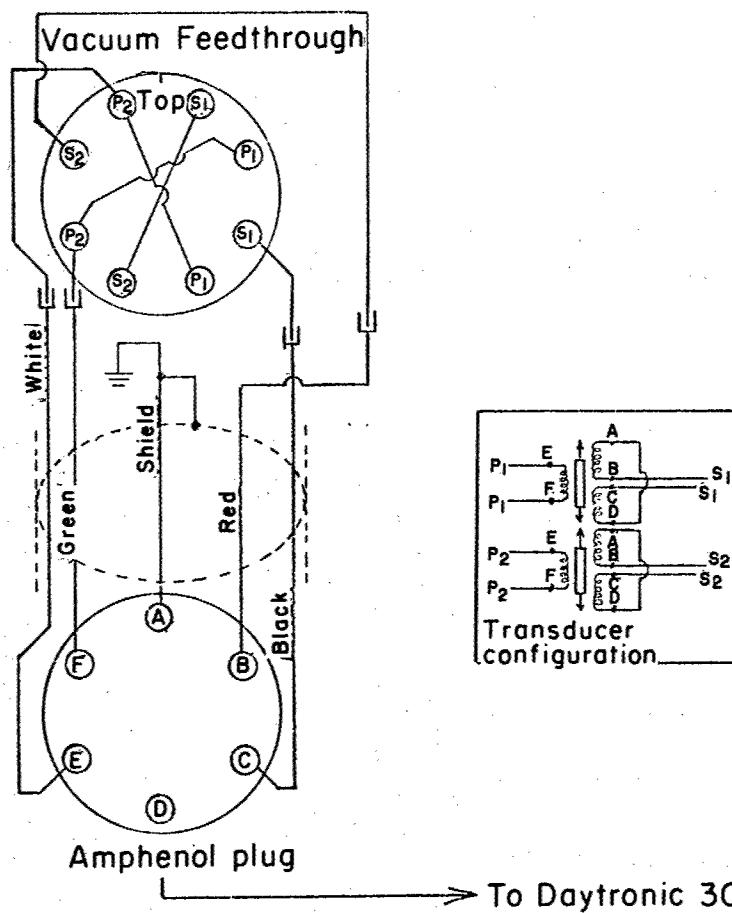
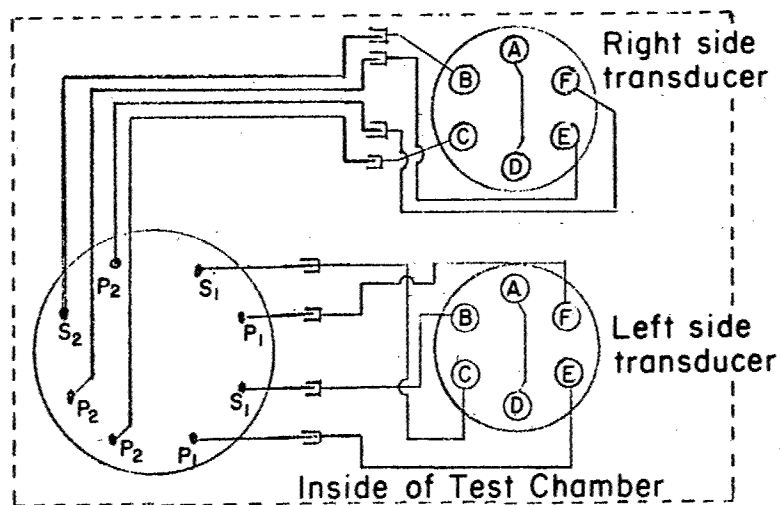


FIGURE 12 TRANSDUCER TO 300D WIRING DIAGRAM

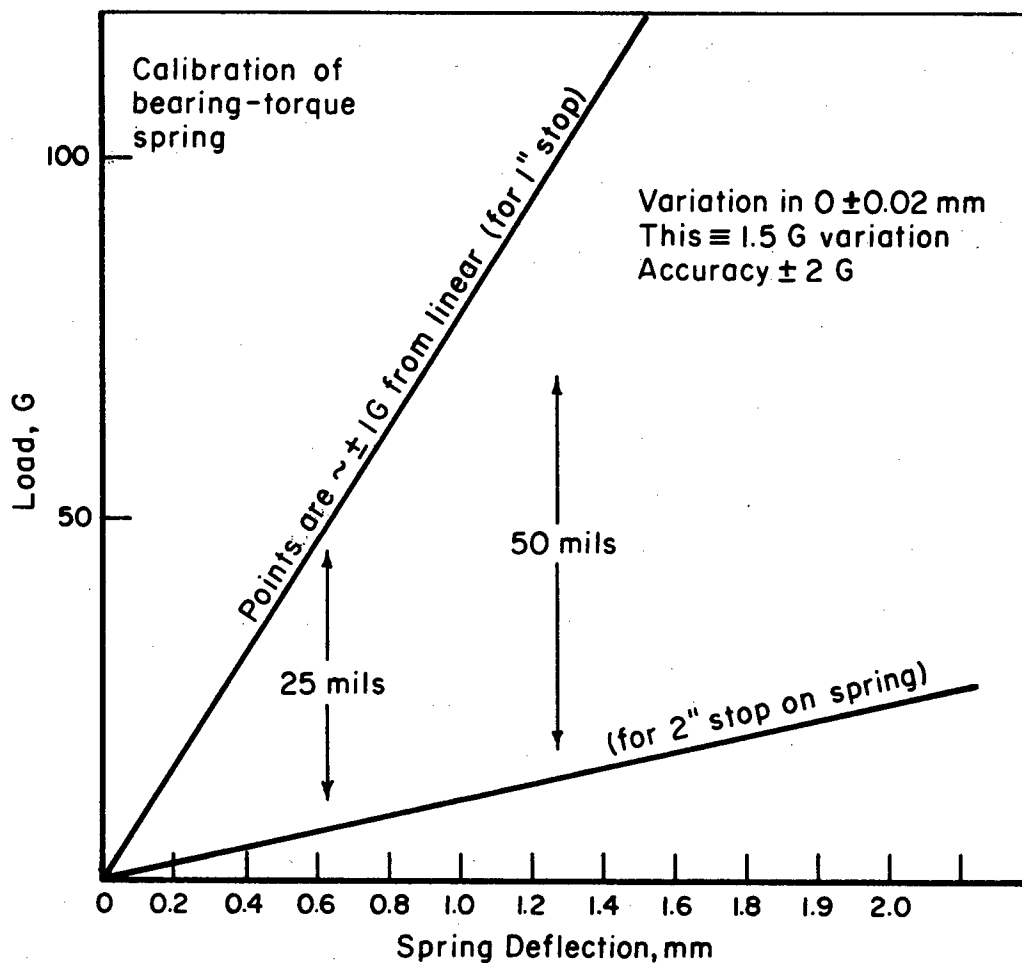
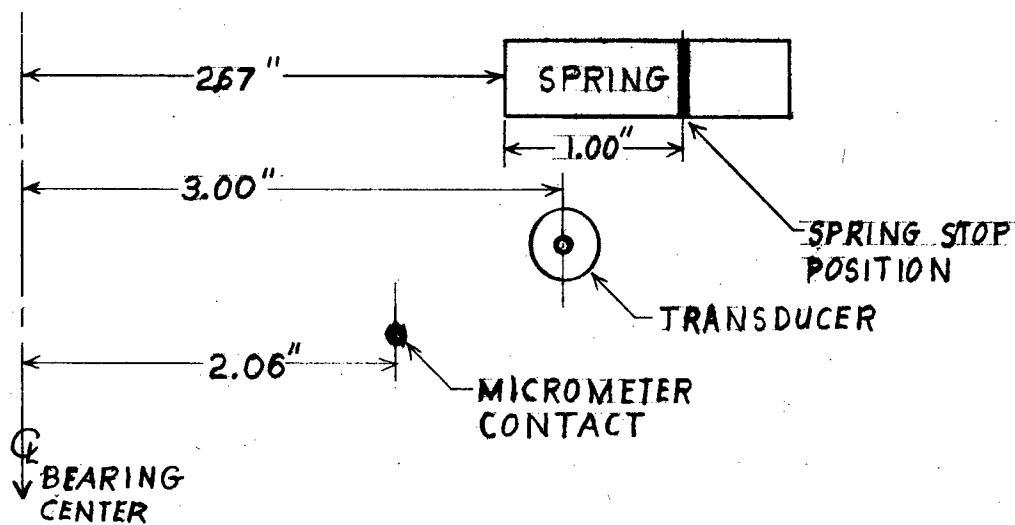


FIGURE 13 COMPONENT GEOMETRY AND SPRING CALIBRATION CURVE

Mounting the Top Closure

The top cover, containing an intruding viewport is installed as follows:

- a. Carefully clean all surfaces.
- b. Select an unblemished copper gasket and place it on the upper chamber flange.
- c. Lower top flange, containing the window, onto the copper gasket. The window must be oriented exactly opposite the load arm. Care must be taken not to damage the glass or its welded kovar seal.
- d. Install flange bolts and tighten evenly.

Connection to Vacuum System

Remove the fixture from the wooden assembly stand and place the motor end on the mounting jack. Clean mating flanges of the FIXTURE and pump. Position an unblemished copper gasket on the flange and connect the two units. Use extreme care not to damage the flanges during assembly. Install and adjust outer end support leg before removing the mounting jack from the FIXTURE.

CALIBRATION PROCEDURES

Load Calibration

A BALDWIN SR-4 load cell, type U3G1, was used to calibrate the hardened tool-steel flat arm which is employed to produce vertical, thrust-loading to the test bearing (Ref. FIGURE 5).

The load cell was hung loosely from a rigidly mounted horizontal beam as shown in FIGURE 9. A length of 35 mil (0.9 mm) diameter music wire was used to connect the internal loading arm clamp to the load-cell eyebolt. With the internal loading arm maintained near its normal (horizontal) position, load was applied by turning the hand screw to effect bending of the vertical leaf spring.

Loads, in microinches/inch, were read on a BALDWIN SR-4, Type N strain indicator and these readings were converted to pounds-force by interpolation from a calibration curve supplied by BCL's Instrument Laboratory. It is estimated that the pound-force readings obtained in this manner have a tolerance of $N \pm 1.5$ pounds.

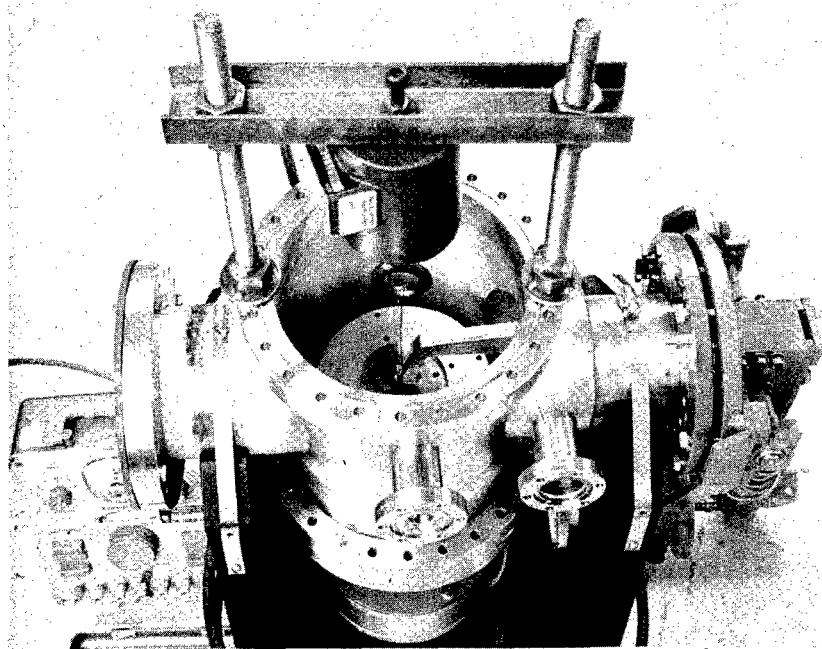


FIGURE 14 METHOD OF LOAD-SPRING CALIBRATION

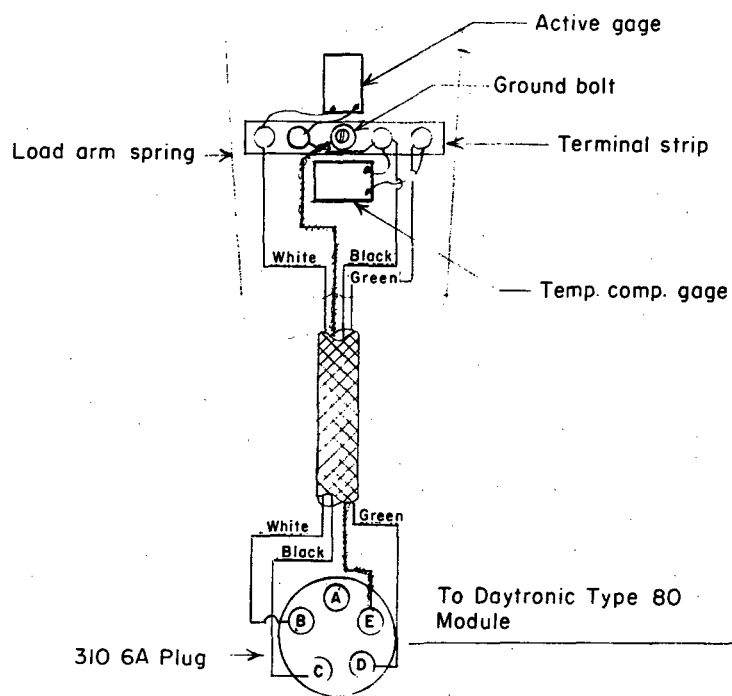


FIGURE 15. LOAD-SPRING TRANSDUCER WIRING

The external, vertical, tool-steel loading spring was instrumented with a single pair of Type A-5, BALDWIN SR-4, strain gages* to form a standard half-bridge configuration. The gages were mounted at right angles to one another (one being perpendicular to the spring axis) in order to provide temperature compensation as well as strain sensitivity. Connection to the gages from the Type 80, DAYTRONIC plug-in (strain gage) unit is made via a doubly shielded 4-wire cable. (The black and red leads are separately shielded.) The connections between strain gages and the AMPHENOL Type MS 3106A-14S-5P plug are as shown in the sketch contained in FIGURE 10. The B and D pin connections are the AC output carrier from the DAYTRONIC transducer amplifier (300C).

The setup and use of the 300C and the Type 80 plug-in unit are as follows:

- a. Set the adjustor on the back panel of the Type 80 plug-in unit for 120Ω (gage factor) on the 2-arm side (right).
- b. After 10 min warm-up set the RANGE SELECTOR (front panel)... (FIGURE 4) to zero and adjust the meter to zero by means of the amplifier ZERO control. Next set the RANGE SELECTOR to NULL and with ZERO load on the instrumented loading arm, adjust both the C (capacitive) and R (resistive) controls for minimum readings.** It may be necessary to lower the amplifier sensitivity by turning the SENSITIVITY control several turns counter-clockwise in order to bring the meter pointer toward zero for the initial null adjustment. The sensitivity should subsequently be increased to maximum for final nulling - which should also be zero on the meter. The RANGE SELECTOR may now be turned to any position without significant meter movement. If a few divisions of movement are present on the most sensitive setting (100 position), the R-NULL (resistance) control should be used to get a zero reading on the meter. The amplifier is now balanced with the half-bridge transducer.
- c. To use the amplifier scale for load application the amplifier sensitivity must first be properly adjusted. To accomplish this, set the RANGE SELECTOR on 25 and the CALIBRATION RESISTANCE on position A; now when the PUSH TO CAL. (red button) is pushed the meter will deflect to the right. The SENSITIVITY control should be adjusted with the CAL. button depressed until a meter reading of 10 (1000 microinches/inch) is obtained. The amplifier sensitivity is now

* Gage factor $2.00 \pm 1\%$ and resistance $119.6 \pm .2$ ohms... Lot No. B-31.

** In adjusting the DAYTRONIC for proper null on Machine No. 2, it will be necessary to employ + SUPPRESSION since the R - NULL lacks sufficient range for zeroing the meter. The amount of + SUPPRESSION to add is approximately 8.0 on the 10-turn vernier dial. After this setting is made the R control is employed to obtain the final zero null and balance adjustment.

adjusted, and full scale (25) is equal to 250 lb load on the specimen.

- d. To set a given bearing load, say 65 pounds, turn the LOAD ADJUSTMENT HANDWHEEL to increase the spring deflection. Adjust until the DAYTRONIC meter reads 650. Finally the large LOCKING HANDWHEEL is employed to lock the loading screw. The amplifier reading, balance, and null should be checked from time to time in order to correct any mechanical drift in the loading mechanism.

Torque Calibration

A DAYTRONIC 300D transducer amplifier-indicator with a Type 70 module may be used to monitor torque and torque ripple in these bearing test fixtures. The wiring diagram is illustrated in FIGURE 7.

To maintain a stable, reproducible calibration, it is essential that the restraining spring rest against its glass stop. It is also important that the spring is not deflected but remains in a no load, nonbent position. One method that can be used to null the spring mechanically is as follows. First move the spring into contact with the stop and lightly wedge it in this position. A short piece of round tubing having a diameter of 0.240 inch is supplied; slide this into the spring stop housing, next to the spring to effect light wedging. After adjustment and calibration, described below, the tubing is removed and the spring will be ready for operation.

Next, the following steps should be used to calibrate the torque measuring system.

- a. Install the calibration micrometer as shown in FIGURE 6. A tiny ball, mounted in a set screw, has been attached to the core support arm in order to provide a reliable contact point for the micrometer. An advance of 35 mils on the micrometer will move the cores 50 mils in each of the transducers. (This is due to the core support arm geometry...illustrated in FIGURE 6.)
- b. With the micrometer out of contact with the ball, the mechanical null point should be found for the right-side transducer. Begin by removing the wire lead from pin S₂, (external end of 8-lead vacuum feedthrough) and attaching it to pin S₁, (Ref. FIGURE 7). This will take the left transducer out of the circuit.

- c. The initial adjustment procedures for the 300D amplifier and Type 70 differential transformer input module should be followed at this time. (Ref. Section C* of the Daytronic instruction manual.) The D setting is recommended for the TRANSDUCER CONDITIONING SELECTOR-switch (for easiest null-balancing. The transformer mechanical null can be found by turning the core support screw in or out. Once the null is found, (core ~ 1/4-inch into coil), the screw should be locked in place with the locking nut.
- d. The left transducer should now be reconnected by removing the S₁ lead (black wire), and slipping it back on the S₂ pin.
- e. The left transducer can now be brought into its null position by turning the core support screw in or out; it should then be locked as before.
- f. Turn the 300D SENSITIVITY control to full clockwise position.
- g. Turn the TRANSDUCER ZERO control to its full clockwise position.
- h. Bring the micrometer into contact with ball on the core support arm assembly. As the micrometer makes contact with this ball, the meter will begin to deflect. Continue from this point and advance the micrometer an additional 35 mils. This will correspond to 50 mils movement of the cores which is the linear range of the transducers. (At this point the calibration spring will be deflected 56 mils, Ref. FIGURE 6.)
- i. By repeatedly adjusting the SENSITIVITY and NULL controls, the meter can be made to read full scale - with the RANGE SELECTOR on 5.
- j. Remove the tubing wedge from behind the restraining spring.

A summary of the above procedures and a typical spring calibration (for spring installed in Machine No. 1 are as follows:

- If the LVDT moves 50 mils (the specified linear range);
then the spring moves $\frac{2.67}{3.00} \times 50 = \sim 56$ mils and
the micrometer moves $\frac{2.06}{3} \times 50 = \sim 35$ mils and
the DAYTONIC SENSITIVITY is adjusted for full scale deflection on the 5 range.
- Then 56 mils = 0.142 cm (equiv. to full range spring deflection);

* Attached.

- And 0.142 cm = 111 g (from graph - FIGURE 6).

Thus: if full scale = 111 g, ea. div. = $\frac{111}{50} = 2.05$ g.

This is equiv. to $2.05 \times 3.67 = 7.54$ g/in./div. (torque).

A REVERSE STOP has also been mounted on the CORE SUPPORT ARM. This must be properly adjusted in order to permit checking the 300D amplifier sensitivity during actual testing. To adjust, turn the micrometer back 35 mils from its null (locked) point and adjust the REVERSE STOP (Ref. FIGURE 6) to limit the CORE SUPPORT ARM reverse travel to this distance. Reversing the METER POLARITY switch, and with the arm counter-rotated, the meter must read full scale. To achieve this, adjust the SENSITIVITY CONTROL to attain full scale. When the chamber is sealed the calibration can be checked by rotating the drive motor by hand in the clockwise (reverse) direction until the REVERSE STOP limits the travel of the support arm. (No spring deflection is involved for this movement.) Again the full scale reading should be indicated - with the RANGE SELECTOR on 5. If the meter reads other than full scale, the SENSITIVITY CONTROL must be used to attain full scale. This returns the amplifier to the same sensitivity as used during original calibration.

OPERATION OF THE DRIVE SYSTEM

A separate instruction manual covering the motor and servo-control system has also been furnished with this equipment.

TEMPERATURE MEASUREMENT CAPABILITY

A chromel-alumel thermocouple feedthrough (CERAMASEAL) has been installed in the outer end of the load arm. Leads pass through glass tubes in the arm and protrude into the test chamber. A chromel-alumel type thermocouple can be positioned at any point within the chamber and connected to these leads.

SECTION C: INITIAL ADJUSTMENT & CALIBRATION, TYPE 70 DIFFERENTIAL TRANSFORMER INPUT MODULE.

Following initial installation with a particular transducer, the following initial adjustments must be performed. Thereafter, the relatively simple operating procedures of Section D can be followed.

1. ZERO CHECK: Turn the RANGE SELECTOR switch to STANDBY (which shorts the amplifier input). Turn the SENSITIVITY control fully clockwise. Turn the METER POLARITY switch to NORMAL. If the output module has a METER switch, turn it to the METER OUT position. Turn the POWER switch ON and allow ten minutes for stabilization. The meter indication should now be within one quarter division from zero. If it is greater than this amount, adjust for exactly zero indication using the mechanical adjustment on the face of the meter. If the output module has a METER switch, turn it now to the METER IN position, and adjust for exactly zero meter indication, using the BALANCE control (if applicable). (If you cannot achieve zero indication, refer to Section E.)
2. TRANSDUCER CONDITIONING SELECTOR: Turn the TRANSDUCER CONDITIONING SELECTOR switch to the proper position for the transducer used, as determined from Table One (next page).
3. TRANSDUCER NULL ADJUSTMENT: Turn the SENSITIVITY*, TRANSDUCER ZERO*, and NULL* controls to the approximate midpoint of their travel. Ascertain that the mechanical input to the transducer is in the condition desired as zero reference. Turn the RANGE SELECTOR to NULL (which converts the instrument to a simple, nonphase sensitive AC voltmeter). Adjust the transducer mechanical zero adjustment (or position) to achieve minimum meter reading. (If the meter remains off scale, reduce the SENSITIVITY setting and try again). Then adjust the NULL control to achieve minimum reading (which should be less than obtained in the previous step). Alternately adjust the mechanical zero adjustment and NULL control until no further reduction in reading can be obtained, turning the SENSITIVITY control fully clockwise in the process to obtain maximum resolution. (NOTE: Minimum null value is usually less than two divisions. If the mechanical zero adjustment is too coarse to permit such adjustment, the final stages of the process may be carried out using the TRANSDUCER ZERO control in lieu of the mechanical zero adjustment.) (If you cannot obtain a satisfactory null value, see Section E.)
4. CALIBRATION: Turn the RANGE SELECTOR switch to the sensitivity range appropriate for the transducer operating range. With zero input to the transducer, adjust for exactly zero indication using the TRANSDUCER ZERO control. Apply, a precisely known value of mechanical input to the transducer. Adjust the SENSITIVITY control to obtain an indication precisely corresponding to the known input. Without disturbing any other controls, turn the RANGE SELECTOR switch to the CAL position. Adjust the CAL REFERENCE control to obtain exactly full scale indication. The system is now calibrated and can be used as described in Section D.

* These controls are ten-turn types with friction drive, which may make it difficult to determine the end of travel. To position in the midpoint, turn at least ten turns in one direction, then turn five turns in the other direction.

APPENDIX III

INSTRUCTION MANUAL

for

ASSEMBLY, CALIBRATION, AND OPERATION OF SLIP-RING TEST FIXTURE

INTRODUCTION

This test fixture has been designed and built to study slip-ring and brush assemblies as used in communication satellites. Programmed testing under conditions that simulate those of space operation are feasible using this equipment. Provisions have been incorporated that permit the measurement of friction, electrical continuity, and temperature. Six slip-ring sets can be mounted in the test device. A servo-controlled DC motor drive system is used to rotate the rings and a 6-inch-diameter glass window is installed in a wall of the stainless steel, vacuum test chamber.

ASSEMBLY OF SLIP-RING DEVICE

Mounting the Slip Rings on the Shaft

Six ELECTRO-TEC slip rings as shown on their drawing No. 43030 have been supplied. These can be mounted on the device shaft in the manner illustrated in FIGURE 11. Close tolerances have been held and rings fit over the shaft with 1-2 mils (0.03-0.06 mm) clearance. Lubricant barrier rings, each of 0.010-inch (0.25 mm) thickness, should be installed between adjacent slip rings. These were not made or installed for the initial assembly.

When mounting the rings it is necessary that steps be taken to maintain their surfaces in the clean, unblemished condition supplied by the manufacturer. White gloves should be worn during handling. Place final spacer on shaft and lock entire assembly with the slip-ring locknut. (A spanner wrench is supplied.)

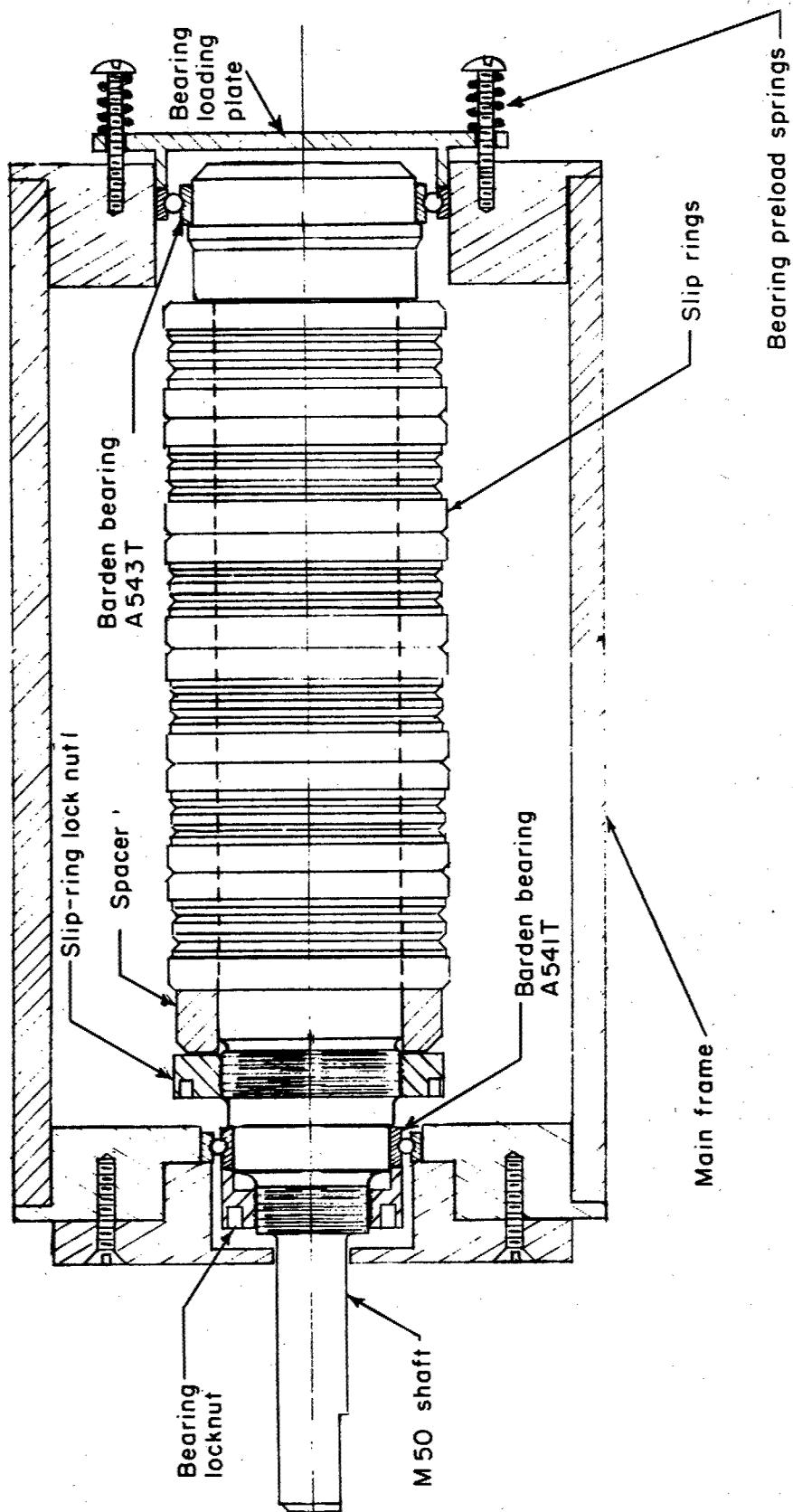


FIGURE 1'6 SKETCH OF ASSEMBLED SLIP-RING DEVICE

Mounting the Shaft Bearings

The bearings are the precision instrument type and must be handled carefully. For the initial assembly the manufacturer's lubricant was not removed. The bearings have a light interference fit and it is necessary to press them into position.

Press the bearings onto the shaft and install the bearing locknut (small bearing end), as shown in the sketch in FIGURE 11. A spanner wrench is provided for this purpose.

Installing the Shaft Assembly

The shaft assembly can now be placed in the device MAIN FRAME (Ref. FIGURE 11). The bearings slide into their supports with a hand press fit.

Installing Bearing Preload Plate

Install the BEARING LOADING PLATE as shown in FIGURE 11. Position the three springs and screws as shown. Tighten the screws to lock them in place. The springs will now apply the proper thrust loading to the bearings.

Mounting MAIN FRAME ASSEMBLY in Test Fixture

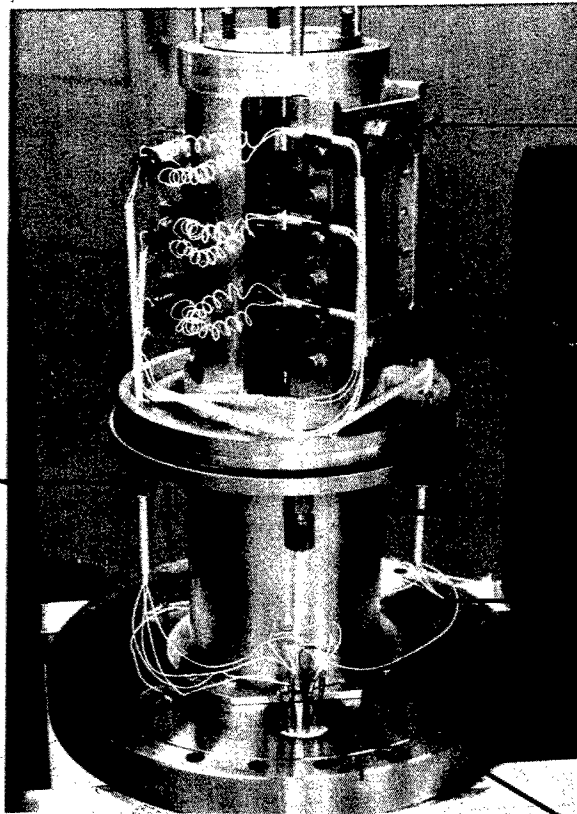
The remainder of the assembly steps may be carried out with the device MAIN FRAME ASSEMBLY mounted on the BOTTOM FLANGE of the test chamber. Attach the ASSEMBLY to the stand-off as shown in FIGURE 12. Bolt into place with three socket cap screws. Place the shaft alignment sleeve* on the FERROFLUIDIC feedthrough end. Set the ASSEMBLY down over the sleeve with the shaft of the ASSEMBLY sliding into the sleeve. Lock the lower end of the STAND OFF to the BOTTOM FLANGE using three bolts. Note that the bolt holes are a loose fit to permit the two shafts to align properly. The machined flat on the lower STAND-OFF flange must be positioned to accommodate the ELECTRICAL FEEDTHROUGH port.

Loosen and remove the MAIN FRAME ASSEMBLY by taking out the three bolts at the device end of the STAND OFF. (The LOWER END PLATE fits into the stand off with a close tolerance.) Remove the alignment sleeve and install the REX NORD coupling. One set screw is to be positioned over the flat on the shaft. A lead shot must be placed under the other setscrew to protect the shaft surface from damage by the screw. Access holes have been machined into the stand-off for operation of an Allen wrench.

* Special sleeves have been provided.

FRONT VIEW

Feedthrough



Brush block
support bracket

Lower end plate

Upper coupling

Stand off

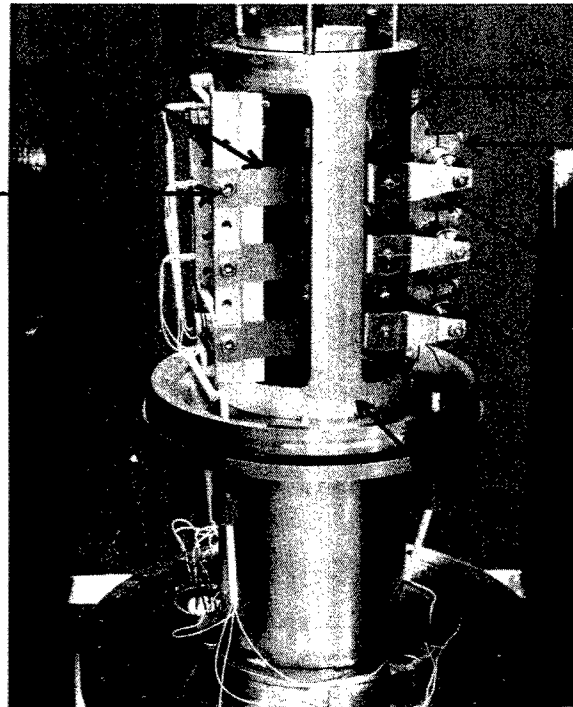
Electrical
feedthrough

Bottom flange
of test chamber

REAR VIEW

Flexible
support arm

Support arm
clamp



Brush block
Transducer
mounting clamp

Transducer
core support

Transducer

Main frame

FIGURE 17. SLIP-RING ASSEMBLY MOUNTED

Replace the MAIN FRAME ASSEMBLY while making sure its shaft slides properly into the coupling. Install the upper-end setscrews in the coupling in the same manner used to install those on the feedthrough end.

When it is necessary to remove the MAIN FRAME ASSEMBLY from the TEST FIXTURE, it should be unbolted at the top of the STAND OFF, leaving the STAND OFF attached to the BOTTOM FLANGE. The FIXTURE was delivered with the shafts properly aligned; realignment becomes necessary only if the STAND OFF is loosened and moved.

LUBRICANT RESERVOIR

If a lubricant reservoir is to be used it should be mounted at this time. A hole has been drilled through the back of the MAIN FRAME and can be used to hold a reservoir sized to fit the available space.

Mounting BRUSH BLOCK BRACKET

Position the bracket on the MAIN FRAME and lock in place with two cap screws as shown in FIGURE 12.

BRUSH BLOCK Installation

Mount the BRUSH BLOCKS on the outer ends of the FLEXIBLE SUPPORT ARMS (Ref. FIGURE 12). The TRANSDUCER CORE SUPPORTS must also be mounted as shown. The screw holes in these support arms have been slotted on their lower ends to permit alignment and loading of brushes. Align the blocks so brush wires fit into the mating grooves in the slip rings. Proper loading of the brushes onto the rings can be accomplished by sliding the FLEXIBLE SUPPORT ARMS in or out.

One technique for adjusting to a desired brush load is: first bring the brushes into contact with the ring (this contact point can be determined using an ohmmeter connected across the brush terminals); then, using a telescoping gage, the distance between the top of the BRUSH BLOCK and the inside of the MAIN FRAME is determined. This distance should be measured in mils. Next a micrometer is set to the proper distance to give the desired brush wire deflection for the load required, and the telescoping gage is adjusted to this measurement. Finally the block is moved in towards the ring until the gage setting is attained between the block and the MAIN FRAME; then, the lower support-arm screws are tightened. The initial load setting is that shown on the ELECTRO-TEC drawing. (i.e., 40 mils = 5-g load.)

Mounting the TRANSDUCERS

Install the TRANSDUCER (linear variable differential transformer) cores and support screws as shown in FIGURE 12.

Mount the TRANSDUCER coils as shown, being careful to align the cores to avoid contact in the coil center holes. (A core must not touch the bore of its transducer coil at any time throughout its total travel of ± 0.05 inch.) Each core should be positioned so that about one-quarter-inch of its mounting screw (i. e. end of core) protrudes into the end of the transducer housing. Lock cores in place on the threaded shafts using locknuts, but leave the TRANSDUCER MOUNTING CLAMP screws loose until null adjustments are completed.

Instrumentation Wiring

Wiring for the TRANSDUCERS and slip rings conforms to the WIRING DIAGRAM shown in FIGURE 13. All leads in the chamber have Teflon® insulation, and the four FEEDTHROUGHS from the inside of the MAIN FRAME ASSEMBLY have Teflon-packed glands. Gold-plated connectors have been installed to provide removable junctions with the ELECTRICAL FEEDTHROUGH plug in the BOTTOM FLANGE.

Calibration of Friction-Measuring System

To calibrate the friction-measuring instrumentation the following method can be used (this was the technique employed during the initial assembly).

- a. The wire brushes are tied back from the slip rings by passing a loop of thread through the center hole of the brush block and under the ends of the two wires. Care must be taken not to bend the wire permanently.
- b. Clamp a free running pulley or a smooth nylon rod in position as shown in FIGURE 14.
- c. Loop another thread under the BRUSH BLOCK and hang it over the pulley as shown.
- d. With no weight on the thread the TRANSDUCER should be mechanically nulled. The DAYTRONIC 300D with Type 70 input module may be used for transducer (differential transformer) readout and Section C of its instruction manual (attached) should be followed for the "nulling" procedure. It may be found that a near zero null point will be impossible to obtain. This is due to the additional reactance of the circuit induced by the leads, connectors, and feedthroughs causing a mismatch with the DAYTRONIC input. In this case the module null adjustment should be set at its midpoint and

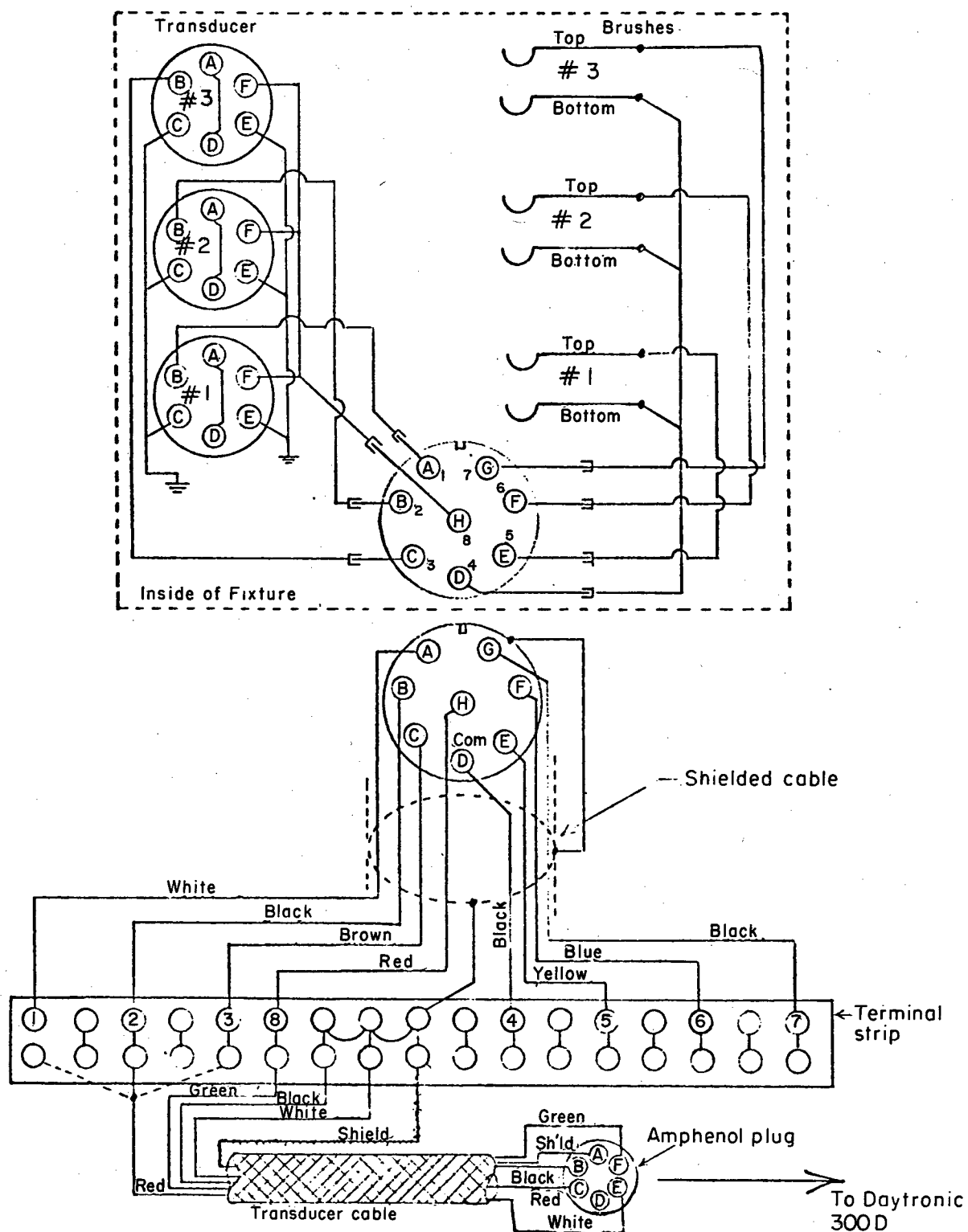


FIGURE 18. WIRING DIAGRAM FOR SLIP-RING ASSEMBLY

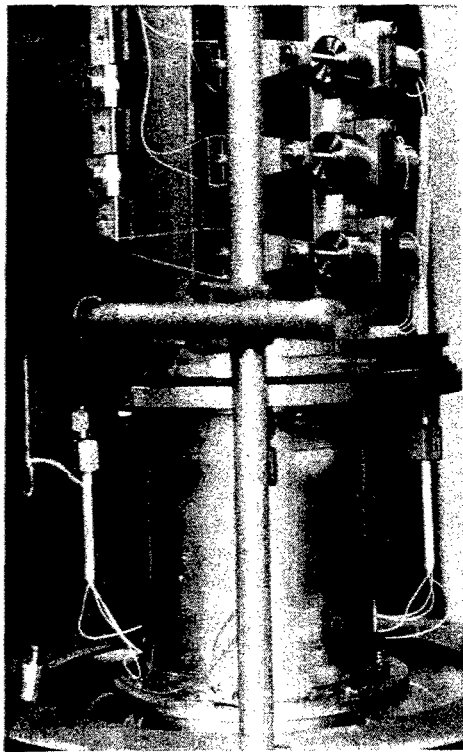


FIGURE 19. TRANSDUCER CALIBRATION

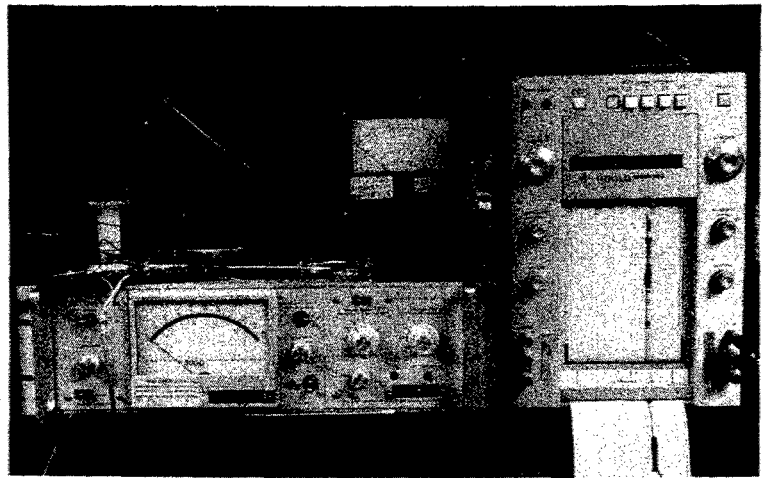


FIGURE 20 INSTRUMENTATION APPLIED TO RECORD SLIP-RING FRICTION

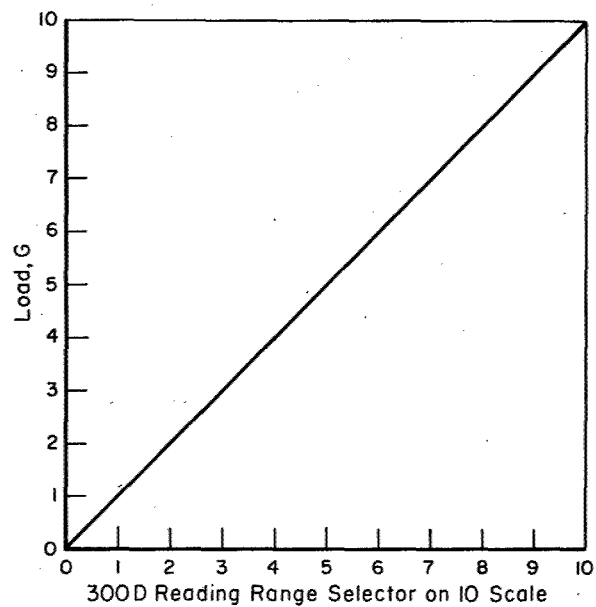


FIGURE 21 FRICTION CALIBRATION DATA (DEAD-WEIGHT LOADING)

the transducer mechanical null adjusted to read approximately zero. While making this adjustment the RANGE SELECTOR must be set on the range at which it will operate during the test. During the initial assembly, range 10 was used on all three transducers. The CAL reference can be adjusted to give a check point for the system which can be used during testing. Full-scale pointer deflection was used during initial calibration.

- e. Add weight to the thread as shown in FIGURE 14. Several different-sized weights should be used to cover the expected range of measurements. With this data, a calibration curve can be drawn as shown in FIGURE 16. A recorder can also be incorporated as shown in FIGURE 15.
- f. With this instrumentation, if more than one transducer is to be monitored during the test it will be necessary to have a Daytronic 300D with Type 70 input module for each; however, there are several alternatives. One possibility would be to use one 300D transducer amplifier and a Type 76 input module. The Type 76 allows manual selection among six input channels, each of which is provided with the necessary individual nulling, calibration, and zero controls. The DAYTRONIC series 800 signal conditioners offers even a wider range of possibilities in that with proper module combinations, all three outputs could be monitored individually and at the same time.
- g. The remaining two TRANSDUCERS should be adjusted and calibrated in exactly the same manner.
- h. Following the calibrations, the pulley and threads should be removed to release the brush wires.
- i. Inspect each slip ring for correct nesting of the brush wires in the slip-ring grooves.

Installing the GLASS HOUSING

Place a Viton® O-ring over the device LOWER END PLATE shoulders (Ref. FIGURE 12). An O-ring groove has been machined into the plate for this purpose; alternatively the O-ring may be positioned as shown. Install the glass sleeve as shown in FIGURE 17 with another O-ring mounted on the UPPER COVER PLATE. Place this in the GLASS HOUSING and install the three thumbnuts as shown.

FIXTURE FINAL ASSEMBLY

With the slip-ring device assembled, calibrated, and mounted on the BOTTOM FLANGE, the final assembly of the FIXTURE can proceed as follows:

Thermocouple Placement

If a thermocouple is to be used inside the test chamber, it should be installed where required. It must be the chromel-alumel type.

Closing of VACUUM CHAMBER

Clean sealing surface of the BOTTOM FLANGE and position a new copper gasket. Lower the chamber over the MAIN FRAME ASSEMBLY and position it on the copper gasket as illustrated in FIGURE 18. If a thermocouple has been installed its lead must be fed through the 1-1/2-inch flange on the lower left side. Install BOTTOM FLANGE bolts and make sure the gasket is properly seated.

THERMOCOUPLE FEEDTHROUGH

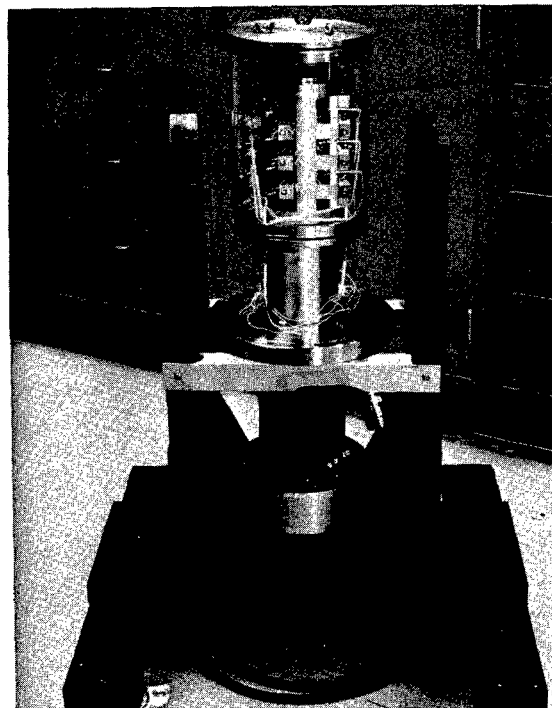
Using wire clamps, connect the chromel-alumel thermocouple to the chromel-alumel leads of the CERAMASEAL. Install the feedthrough with a copper gasket and connect the outside plug which should contain chromel-alumel extension wires.

Vacuum-Gage Installation

Install the nude-type ion gage (VARIAN) in right side 1-1/2-inch vacuum flange.

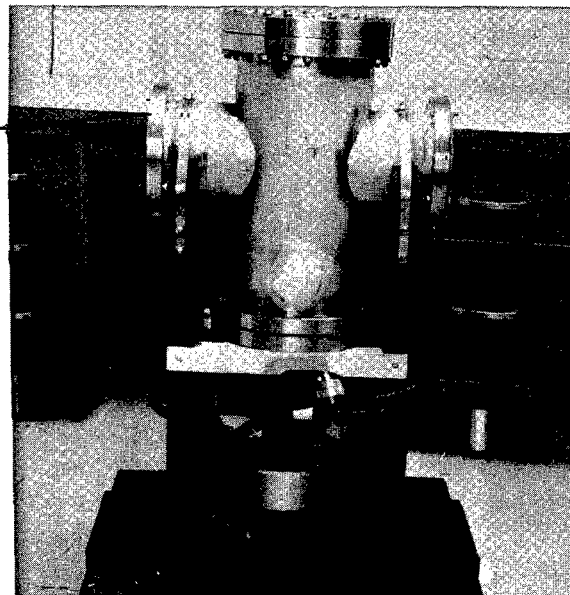
Mounting the Viewing Window

Mount the 6-inch vacuum-bakeable window on the REAR FLANGE as shown in FIGURE 18.



Glass outer
housing

FIGURE 22 SLIP-RING TEST FIXTURE - ASSEMBLED



Rear flange

Vacuum pump
flange

FIGURE 23 SLIP-RING TEST FIXTURE WITH VACUUM
HOUSING INSTALLED

Connecting Fixture to Vacuum Pump

Remove the TEST FIXTURE from the wooden ASSEMBLY STAND and place its motor end on the mounting jack. Clean mating flanges of the FIXTURE and pump (or interconnecting plumbing). Position a copper gasket on the flange and bolt the flanges together. Be very careful not to damage the flanges' sealing edges during assembly. Install and adjust the outer-end support leg, then remove the mounting jack.

Operation of the Drive System

Connect the TEST FIXTURE motor cord to the outlet on the motor controller panel. An instruction manual for the assembly and operation of this panel has been prepared and furnished. This manual explains the proper adjustment and operation of the unit.

SECTION C: INITIAL ADJUSTMENT & CALIBRATION, TYPE 70 DIFFERENTIAL TRANSFORMER INPUT MODULE.

Following initial installation with a particular transducer, the following initial adjustments must be performed. Thereafter, the relatively simple operating procedures of Section D can be followed.

1. ZERO CHECK: Turn the RANGE SELECTOR switch to STANDBY (which shorts the amplifier input). Turn the SENSITIVITY control fully clockwise. Turn the METER POLARITY switch to NORMAL. If the output module has a METER switch, turn it to the METER OUT position. Turn the POWER switch ON and allow ten minutes for stabilization. The meter indication should now be within one quarter division from zero. If it is greater than this amount, adjust for exactly zero indication using the mechanical adjustment on the face of the meter. If the output module has a METER switch, turn it now to the METER IN position, and adjust for exactly zero meter indication, using the BALANCE control (if applicable). (If you cannot achieve zero indication, refer to Section E.)
2. TRANSDUCER CONDITIONING SELECTOR: Turn the TRANSDUCER CONDITIONING SELECTOR switch to the proper position for the transducer used, as determined from Table One (next page).
3. TRANSDUCER NULL ADJUSTMENT: Turn the SENSITIVITY*, TRANSDUCER ZERO*, and NULL* controls to the approximate midpoint of their travel. Ascertain that the mechanical input to the transducer is in the condition desired as zero reference. Turn the RANGE SELECTOR to NULL (which converts the instrument to a simple, nonphase sensitive AC voltmeter). Adjust the transducer mechanical zero adjustment (or position) to achieve minimum meter reading. (If the meter remains off scale, reduce the SENSITIVITY setting and try again). Then adjust the NULL control to achieve minimum reading (which should be less than obtained in the previous step). Alternately adjust the mechanical zero adjustment and NULL control until no further reduction in reading can be obtained, turning the SENSITIVITY control fully clockwise in the process to obtain maximum resolution. (NOTE: Minimum null value is usually less than two divisions. If the mechanical zero adjustment is too coarse to permit such adjustment, the final stages of the process may be carried out using the TRANSDUCER ZERO control in lieu of the mechanical zero adjustment.) (If you cannot obtain a satisfactory null value, see Section E.)
4. CALIBRATION: Turn the RANGE SELECTOR switch to the sensitivity range appropriate for the transducer operating range. With zero input to the transducer, adjust for exactly zero indication using the TRANSDUCER ZERO control. Apply, a precisely known value of mechanical input to the transducer. Adjust the SENSITIVITY control to obtain an indication precisely corresponding to the known input. Without disturbing any other controls, turn the RANGE SELECTOR switch to the CAL position. Adjust the CAL REFERENCE control to obtain exactly full scale indication. The system is now calibrated and can be used as described in Section D.

* These controls are ten-turn types with friction drive, which may make it difficult to determine the end of travel. To position in the midpoint, turn at least ten turns in one direction, then turn five turns in the other direction.

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13. ABSTRACT Three experimental apparatuses have been designed, constructed, and delivered to the Air Force Materials Laboratory. These apparatuses will be used to develop experimental data which can be used to devise accelerated life tests for bearings and slip rings for mechanically despun antenna drive systems for Air Force communications satellites. Two apparatuses were designed for the purposes of studying lubricant degradation and dewetting in ball bearings operating in vacuum. The third apparatus was designed to evaluate lift tests for slip rings operating in vacuum. The report appendices contain operating instructions for the various apparatuses.			

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14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	Bearing test fixtures Slip-ring test fixture Despun antenna drive mechanisms Dewetting of bearing contacts Lubricant degradation Lubricant performance Bearing life studies Bearing performance Slip-ring and brush wear Slip-ring and brush performance Slip-ring and brush friction						

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